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MIDDLE ORDOVICIAN LIMESTONES FROM LEE COUNTY VIRGINIA TO CENTRAL KENTUCKY[1]

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ABSTRACT

Limestones previously mapped as "Lowville" in Lee County, Virginia, between the cherty "Lenoir" and "Trenton" have lithologic and faunal zones that correlate with units to the east in Virginia and north in Kentucky.

The lower 250–300 feet of "Lowville" is stratigraphically similar to the "Ottosee" of Rye Cove, Virginia. The succeeding 550 feet has a thin *Stromatocerium* zone 65 feet above the base, one of *Hesperorthis* 10 feet higher; the base of a 100-foot zone with *Cryptophragmus* and *Camarocladia* is 55 feet above. The *Cryptophragmus* zone is lower "Moccasin" at Rye Cove, Virginia, and upper Camp Nelson in Kentucky. The upper 150 feet (Eggleston mud-rock facies) is the equivalent of the Tyrone of Kentucky; the two thick metabentonites in the Eggleston are like those in the Tyrone.

The Eggleston is overlain conformably by 40 feet of crystalline limestone carrying a Curdsville fauna. The succeeding 60–70 feet of alternating shale and limestone grading upward into yellow-brown, calcareous shale has the fauna of the Logana ("Hermitage") of Kentucky. The overlying "Catheys-Cannon" seems to correspond to middle and upper Trenton of Kentucky.

Lower Trenton age of the Eggleston and Tyrone is indicated by their conformability with the overlying Curdsville, which is homotaxial with the Kirkfield (Hull). Correlation of the Oregon is uncertain. The *Cryptophragmus* beds correspond to the Benner of Pennsylvania, classed as Black River Pamelia and Lowville.

INTRODUCTION

Middle Ordovician limestones have been known to outcrop extensively in Lee County, extreme western Virginia,[2] but their stratigraphy has been discussed only superficially, no detailed study having been undertaken. The section in the center of the Jessamine dome in Kentucky, 150 miles northwest, although unexposed at the base, has been described more adequately. Lee County lies intermediate between the thick clastic section of the Middle Ordovician geosyncline in Virginia and the thinner limestone section in Kentucky; an understanding of its stratigraphy is therefore important. The writer determined the lithologic units in Lee County and recognized corresponding units in Kentucky. Subsurface studies previously showed northwestward thinning in the latter state;[3] the present work reveals the manner of convergence. More precise dating of the St. Peter sandstone is made possible. Subsequent to the completion of field

[1] A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University (1944).

[2] Charles Butts, "Geologic Map of the Appalachian Valley in Virginia," *Va. Geol. Surv. Bull.* 42 (1933), pp. 1–50 with map.

[3] L. B. Freeman, "Present Status of St. Peter Problem in Kentucky," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXII (1939), pp. 1836–43.

study, similar rocks were described and classified in Tazewell County, Virginia,[4] 50 miles northeast of Lee County. Correlations can be carried between previously unrelated Appalachian and Kentucky sections. The regional stratigraphy is not adequately known, but progress is being made and the whole is gradually coming to form a co-ordinated picture.

The original plan was (1) to study and zone the Middle Ordovician rocks in Lee County, Virginia, and (2) to compare similar rocks in Kentucky. The need for suitable stratigraphic nomenclature for the Lee County section prompted investigation of regional stratigraphy of the Middle Ordovician of southwestern Virginia. The study results in a classification of the strata in Lee County (see Table 1). Since the field work was completed prior to publication of new nomenclature proposed for Tazewell County,[5] use of older terminology seems advisable; questionable formation names are placed in quotation marks. Inasmuch as study of the extension of the Tazewell units has been undertaken,[6] application of new stratigraphic names is withheld though comparisons are made.

STRATIGRAPHY OF THE LEE COUNTY SECTION

Regional Setting

Lee County lies near the outer edge of the folded Appalachian belt in the most northwestwardly thrust block where the sedimentary rocks form the broad, asymmetrical Powell Valley anticline extending from Tennessee into southwestern Virginia and plunging northeastward into Wise County. The Powell Valley anticline is part of the Cumberland thrust block,[7] a rectangular mass about 125 miles long and 25–30 miles wide, bounded on the northwest by the Pine Mountain thrust fault, on the southwest by the Jacksboro tear fault, on the northeast by the Russell tear fault, and on the southeast by a pair of parallel faults, the Hunter Valley thrust and the Wallen Valley thrust. These relations are shown in Figure 1. The Lee County sections are, for the most part, on the limbs of the Powell Valley anticline. The Glass Store or Hunter Gap section is south of the Wallen Valley fault; Rye Cove, Scott County, is south of the Hunter Valley thrust (Fig. 2).

The principal geosyncline of the Middle Ordovician seems to have been defined by a flexure about 25 miles southeast of the Powell Valley anticline near the present Saltville thrust. Thick clastic sediments (Blount Group) have been considered to disappear along this line, although recent studies indicate that they converge and grade into limestone at the flexure. The strata northwest of this line are in several thrust slices; beds deposited in farther separated areas have come into closer proximity. Attempts to account for the differences in lithologies and faunas of beds in adjacent blocks have resulted in several interpretations of the paleogeography and stratigraphy.

[4] B. N. Cooper and C. E. Prouty, "Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia," *Bull. Geol. Soc. Amer.*, Vol. LIV (1943), pp. 819–86.

[5] *Ibid*, p. 884, Fig. 3.

[6] Prouty, "Middle Ordovician Limestones in the Median and Northwest Belts of Virginia and Tennessee" (abstr.), *Bull. Geol. Soc. Amer.*, Vol. LII (1941), pp. 1973–74.

[7] C. K. Wentworth, "Russell Fork Fault of Southwestern Virginia," *Jour. Geol.*, Vol. XXIX (1921), pp. 351–69; Charles Butts, "Fensters in the Cumberland Overthrust Block in Southwestern Virginia," *Va. Geol. Surv. Bull. 28* (1927), pp. 1–12; J. L. Rich, "Mechanics of Low-angle Overthrust Faulting as Illustrated by Cumberland Thrust-Block, Virginia, Kentucky, and Tennessee," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XVIII (1934), pp. 1584–96.

The Lee County sections lie wholly north of the Middle Ordovician geosyncline on the continental shield or craton in a position between the thick clastic sections southeast of the Saltville thrust and the central Kentucky section. By careful tracing of lithologic and faunal zones from one thrust block to another, it is possible to establish correlations with sections nearer the geosyncline.

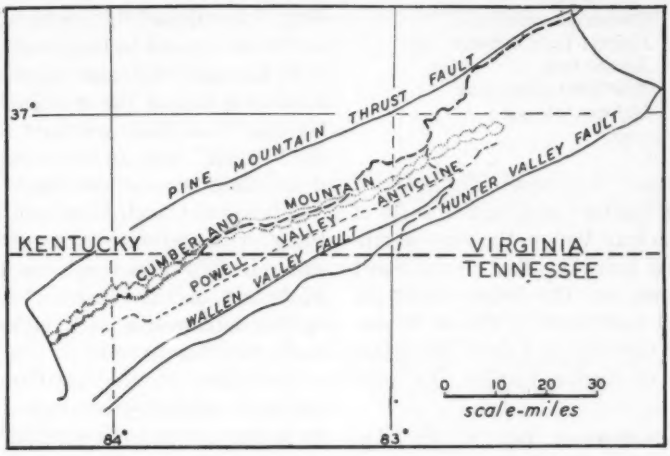

FIG. 1.—Cumberland overthrust block (after Rich, Butts, and others)

FIG. 2.—Index map showing location of sections in southwestern Virginia

EARLIER INTERPRETATIONS OF REGIONAL STRATIGRAPHY

In the southeastern belt of the Appalachian Valley, southeast of the Salt-

ville thrust, Butts[8] has proposed the following lithologic succession:

Lowville-Moccasin
Blount Group
  Ottosee limestone
  Hiatus: Tellico absent
  Athens shale
  Whitesburg limestone
  Holston limestone
Lenoir

The "Ottosee" was reportedly confined to the southeastern and median belts of the Appalachian Valley, the most northern outliers being at Rye Cove, Scott County, Virginia. The Athens shale did not extend northwest of Clinch Mountain or of the line of Clinch Mountain northwest of Burkes Garden, Tazewell County.

In the northwest belt of the Appalachian Valley, including Lee County, the rocks between the Beekmantown and the Cincinnatian (Reedsville) were mapped as (1) Stones River, (2) Lowville, and (3) Trenton.[9] The "Stones River" included the "Mosheim" and "Lenoir." The "Lowville" of Butts comprised 1,000 feet of dove-gray limestone and mud rock. Where the "Lowville" passes into red mud rock, the name "Moccasin" was applied. In areas transitional between the dominantly limestone facies and the dominantly mud-rock facies, Butts applied the term "Lowville-Moccasin." The overlying "Trenton Group" comprising the "Cannon" and "Catheys" limestones has been called middle and upper Trenton. The name "Eggleston" has been applied to a sequence of beds transitional between the Moccasin and Trenton; these beds are considered by some to be an upper shaly facies of the "Lowville-Moccasin."[10] Beds of lower Trenton age were considered absent in Wise County, east of Lee County;[11] however, R. E. Bates[12] and Butts[13] mentioned the possibility of lower Trenton strata in Lee County.

In Lee and Highland counties, in the northwest belt of the Appalachian Valley, the "Lowville" was said to rest on the "Lenoir" with an intervening hiatus due to the absence of the Blount Group.[14] Southeast of Clinch Mountain, the "Ottosee" reportedly rests on the Athens shale; in two belts northwest of Clinch Mountain, on the "Holston" limestone; farther northwest as at Rye Cove it succeeds the "Lenoir."[15]

Variations in the stratigraphic sequence in adjoining belts were attributed by earlier writers to parallel barriers separating the Appalachian geosyncline into several troughs of sedimentation,[16] a theory later modified by postulation of successive downwarpings from one trough to another.[17] P. E. Raymond[18] suggested that observed differences in adjoining belts might be due to distance from shore, depth of water, and other local

[8] "Geology of the Appalachian Valley in Vir-Virginia," *Va. Geol. Surv. Bull. 52* (1942), p. 148.

[9] Butts, pp. 1–50 of ftn. 1 (1933).

[10] R. R. Rosenkrans, "Stratigraphy of Ordovician Bentonite Beds in Southwestern Virginia," *Va. Geol. Surv. Bull. 46* (1936), pp. 85–112.

[11] G. W. Stose *et al.*, "Geology and Mineral Resources of Wise County and the Coal-bearing Portions of Scott County, Virginia," *Va. Geol. Surv. Bull 24* (1923), pp. 22–28.

[12] "Geology of Powell Valley in Northeastern Lee County, Virginia," *Va. Geol. Surv. Bull. 51* (1939), pp. 37–94.

[13] Pp. 1–12 of ftn. 6 (1927).

[14] Butts, p. 178 of ftn. 7 (1942).

[15] *Ibid.*, pp. 170–71.

[16] E. O. Ulrich and Charles Schuchert, "Seas and Barriers of Eastern North America," *N.Y. State Mus. Bull. 52* (1902), pp. 633–62.

[17] Ulrich, "Revision of Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. XXII (1911), p. 292.

[18] "Middle Ordovician of Virginia and Tennessee" (abstr.), *Bull. Geol. Soc. Amer.*, Vol. XXX (1926), p. 137.

conditions with possible continuous deposition from early Chazyan to late Trenton, except for slight emergence of short duration during and after Lowville.

Earlier interpretations of the Chazyan (Blount Group) have been challenged by Cooper and Prouty.[19] In Tazewell County and elsewhere in Virginia and Tennessee, they have divided the strata between the Beekmantown and Trenton into twenty-eight lithologic and faunal zones, constituting six formations. They state that many of the beds formerly assigned to the Blount group are of Stones River and Black River age; that "Mosheim" has been applied to two different limestones separated by 200–500 feet of beds; and the "Lenoir" of western Tazewell County is considerably older than "Lenoir" of the northwestern part of the county. Further, some of the beds called "Holston" overlie beds with a "Lowville" fauna. Cooper[20] has stated that the Athens formation is more extensive than previously believed; northwest of Clinch Mountain the Athens is represented by a limestone facies. In their final paper, which appeared after the writer had completed his field work, Cooper and Prouty[21] proposed a new system of classification for the Chazyan and Black River sequence in Tazewell County; they state that further use of the names Murfreesboro, Mosheim, Lenoir, Holston, Ottosee, Lowville, and Lowville-Moccasin, unless qualified, is inadvisable.

Stratigraphic Sequence

By way of introduction to a detailed discussion of the stratigraphy of Lee County, the major units which the writer has succeeded in distinguishing are summarized in Table 1. As previously indicated, traditional names are used; these will be found justified in the succeeding pages.

TABLE 1

STRATIGRAPHIC SUMMARY OF MIDDLE ORDOVICIAN OF LEE COUNTY

Description of Unit	Feet
"Catheys-Cannon": Blue, granular, even-bedded, fossiliferous limestone, thickness about	500
Hermitage: Calcareous shale (Zone 20) passing downward into gray, thin-bedded, fine- to medium-textured limestone and shale (Zones 19 and 18); abundant *Sinuites* and *Dalmanella*	60–70
Curdsville: Gray-blue, coarsely crystalline, thin to medium-bedded limestone (Zone 17) including at its base the "cuneiform" beds (Zone 16); characterized by *Sowerbyella curdsvillensis* and *Dinorthis pectinella*	40
Eggleston: Assemblage of yellow, calcareous mud rock and dove limestone (Zone 15) with a thin metabentonite at the base; two thick metabentonites 40 feet apart near the top	150
Moccasin: 135 feet of dove-gray, laminated limestone (Zone 14) underlain by a thick unit of yellow-green mud rock (Zone 13)	300
"Lower Moccasin": Dove-gray, sublithographic to medium-crystalline limestone with well-defined zones of *Stromatocerium, Hesperorthis, Camarocladia, Cryptophragmus* (Zones 7–12)	250
"Ottosee": Dove-gray to bluish-gray, locally argillaceous limestone with a bed of yellow, shaly limestone and red mud rock at the top and lenses of coarsely crystalline limestone near the middle (Zones 1–6)	300
"Lenoir": Dove-gray to brown, dense to finely crystalline, very cherty limestone	200
"Mosheim": Light-gray, sublithographic, thick-bedded limestone	25
"Murfreesboro": Sequence of basal conglomerate, silver-gray shale, red dolomite, and buff dolomite	85

[19] "Chazyan and Black River Stratigraphy in Tazewell County, Virginia" (abstr.), *Bull. Geol. Soc. Amer.*, Vol. LI (1940), p. 1924; Prouty, pp. 1973–74 of ftn. 5 (1941).

[20] "Athens Equivalents Northwest of Clinch Mountain in Southwestern Virginia" (abstr.), *Bull. Geol. Soc. Amer.*, Vol. LII (1941), p. 1893.

[21] Pp. 819–86 of ftn. 3 (1943).

This sequence is underlain by the Beekmantown dolomite and overlain by the Reedsville shale (Cincinnatian). Several exposures of "Stones River" are found in Lee County; hence a brief description of these units is included.

"STONES RIVER" OF PREVIOUS REPORTS

"MURFREESBORO" FORMATION

The Beekmantown dolomite is overlain unconformably by approximately 85 feet of red shale, red argillaceous dolomite, silver-gray shale, and buff dolomite. A prominent conglomerate containing angular fragments of chert and dolomite in a matrix of dolomite is at the base. This "Blackford" facies,[22] formerly included in the Beekmantown, is widely distributed in Lee County; good exposures can be seen along the railroad at Hagan, Virginia. The basal conglomerate shows in the field south of the highway east of Gibson Station, Virginia. There are additional exposures west of Arthur, Tennessee.

A section of a second facies, the "St. Clair" along Yellow Branch Creek, $5\frac{1}{2}$ miles southeast of Rose Hill has been described by Butts.[23] The relationship of the two facies has not been deduced from a study of the Lee County sections.

"MOSHEIM" FORMATION

The "Mosheim" limestone conformably overlies the "Murfreesboro" of Butts. The "Mosheim" is a light-gray, thick-bedded, sublithographic limestone (calcilutite) which breaks with a conchoidal fracture and weathers to rounded or fluted masses with a light-gray surface. About 25 feet is present in Lee County.

[22] Butts, p. 126 of ftn. 7 (1942).

[23] *Ibid.*, pp. 120–21.

"LENOIR" FORMATION

The "Lenoir," succeeding the "Mosheim," is a dove-gray to brown, dense to finely crystalline, thick-bedded limestone with large nodules of black chert which are especially abundant in the upper part. Good fossils are scarce, but remains of *Tetradium* are common on weathered surfaces. *Girvanella*, *Maclurites*, and *Gonioceras* also occur. The "Lenoir" is 150–200 feet thick in Lee County; it thickens southwestward into Tennessee, where as much as 150 feet of dove-gray, thin-bedded, somewhat shaly limestone intervenes between the "Mosheim" and the 95 feet of cherty upper "Lenoir" near Arthur, Tennessee.

"LOWVILLE" AND "TRENTON" OF PREVIOUS REPORTS

INTRODUCTION

The strata between the cherty "Lenoir" of Butts and the "Catheys-Cannon" limestone in Lee County can be divided into at least twenty lithologic and faunal zones (see Fig. 3). Zones 1 through 15 were included in the "Lowville" of Butts, so classified on the presence of *Cryptophragmus antiquatus* Raymond and *Tetradium cellulosum* (Hall), which were considered the invariable guide fossils of the Lowville from Ontario to Alabama. *C. antiquatus* is now known to occur throughout the Pamelia limestone of New York and Ontario while *T. cellulosum* ranges into the Trenton. Zones 16 through 20 were included in the "Trenton" of previous reports. Zones 1–6 are probably best developed in southeastern Lee County along the strike from Dickerson Ford and Glass Store to Deep Spring School, while Zones 7–20 are well developed in central Lee County in the vicinities of Harrogate, Tennessee, Hagan, Virginia, and Turkey Cove, Virginia.

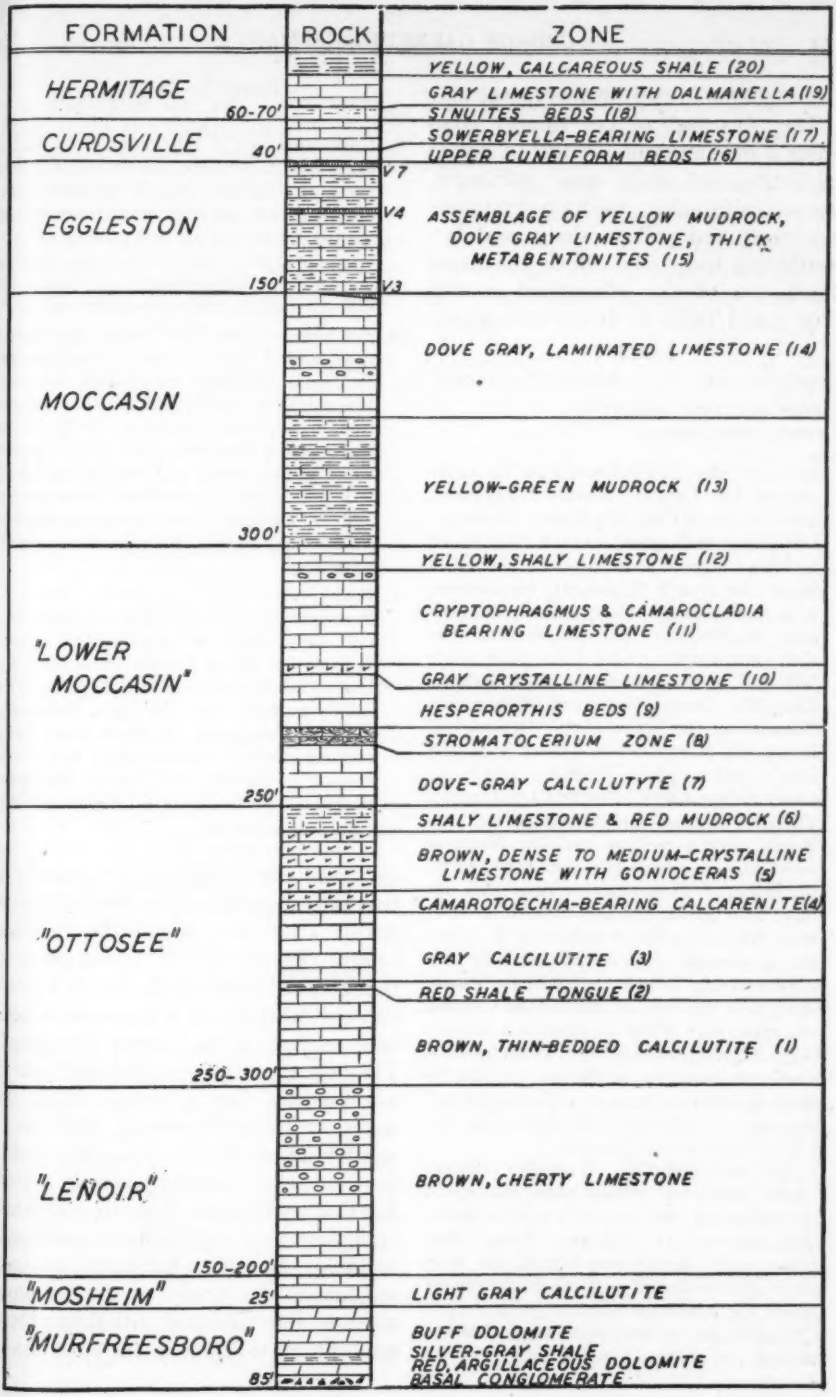

FIG. 3.—Middle Ordovician columnar section for Lee County, Virginia

"OTTOSEE" FORMATION (ZONES 1–6)

The "Ottosee" of Lee County comprises a maximum of 325 feet of brown calcilutite, red shale, gray calcilutite, coarse calcarenite, medium-crystalline limestone, and yellow, shaly, nodular-weathering limestones which constitute Zones 1–6 of the generalized section (Fig. 3 and Table 2). It lies with apparent conformity on the "Lenoir"; a boundary between the formations is drawn arbitrarily where the massive, brown, cherty "Lenoir" gives place to thin-bedded, platy calcilutite. It is overlain conformably by a sequence of beds here referred to as "Lower Moccasin." The best exposures of "Ottosee" are in southeastern Lee County, where the zones are fully developed. Northwestward many of the zones pass into calcilutite and their identity is lost. In central Lee County the lower beds are somewhat argillaceous with ripple marks and fucoid markings. About 150 feet above the base are lenses of coarsely crystalline limestone of the "Holston" lithology; these are believed to represent the most north-

TABLE 2

SUBDIVISIONS OF THE "OTTOSEE" FORMATION

"LOWER MOCCASIN" FORMATION

"OTTOSEE" FORMATION

Zone

6. *Shaly limestone and red mud rock:* In southeastern Lee County, notably Glass Store, and Dickerson Ford, the brown, crystalline *Gonioceras* beds pass upward into shaly, nodular-weathering limestones. At Glass Store this zone is abundantly fossiliferous, with numerous *Dinorthis*, *Sowerbyella*, *Öpikina*, *Multicostella*, and *Strophomena*. The beds pass southeastward into yellow shale and thin beds of limestone with *Öpikina*, *Dinorthis*, *Chasmatopora*, and other genera common to the upper shaly "Ottosee" of Rye Cove. Northwestward these beds pass into a yellow, shaly limestone which becomes red mud rock in central Lee County. Thickness in Lee County about 25 feet.
5. *Brown, dense to medium-crystalline limestone with Gonioceras:* In southeastern Lee County, the granular, *Camarotoechia* beds pass upward into brown, medium-crystalline limestone with a maximum thickness of 75 feet and an average of 50 feet. These beds pass northwestward into dense limestone, locally shaly near the base. In central Lee County, the upper part of this zone forms a massive ledge of dove-gray, calcilutite which becomes *Gonioceras*-bearing near Hagan, Virginia. In southeastern Lee County, *Gonioceras*, etched outlines of *Lophospira*, *Girvanella*, and trilobite fragments are common.
4. *Camarotoechia-bearing calcarenite:* Coarse, friable, somewhat pinkish calcarenite which resembles the "Holston" lithology of Butts. Well exposed at Dickerson Ford, Glass Store, and Deep Spring School, the zone thins northwestward to form discontinuous lenses, the maximum thickness being 35 feet. Characterized by numerous, large *Camarotoechia*.

TABLE 2—*Continued*

Zone

3. *Gray calcilutite:* A maximum of 72 feet of gray, sub-lithographic, massive-bedded limestone with numerous calcite stringers. There are numerous outlines of *Lophospira* near the top. The strata are best exposed at Dickerson Ford and Glass Store, becoming thinner-bedded northwestward; in central Lee County they resemble the underlying Zone 1.
2. *Red shale tongue:* The brown, thin-bedded calcilutite of Zone 1 passes upward into yellow, shaly limestone with a thin tongue of red, calcareous shale. The red shale tongue, well exposed at Dickerson Ford, can be traced along the strike from Yellow Branch Creek to the vicinity of Deep Spring School. It is not exposed in the Glass Store section, and its identity is lost northwestward in central Lee County. Thickness never exceeds a few feet.
1. *Brown, thin-bedded calcilutite:* Brown to dove-gray, dense, thin-bedded limestone lying conformably on the massive, cherty "Lenoir" of Butts. Locally it contains yellow, earthy limestones which weather with a cobbly surface, near the base. Frequently there are thin bands of black chert along bedding planes. It becomes shaly and fucoid-bearing in central Lee County. Maximum thickness is about 140 feet at Dickerson Ford.

"LENOIR" FORMATION

ward spread of the coarse calcarenite (Zone 4) of the southeastern sections. The upper part of the "Ottosee" of central Lee County has 25 feet of yellow, shaly limestone which passes upward into red mud rock. This is persistent, can be mapped, and appears to be at the same horizon as the shaly, nodular-weathering, fossiliferous beds (Zone 6) of the southeastern sections; in both cases the *Stromatocerium* zone of the "Lower Moccasin" lies 65–70 feet above.

TABLE 3

FAUNA FROM THE DINORTHIS BED, ZONE 6

	Locality	
	1	2
Dystactospongia sp.	.....	×
Mesotrypa sp.	×	×
Pachydictya sp.	×	×
Camarella sp.	.....	×
Dinorthis sp.	.....	×
Dinorthis transversa Willard	×	×
Dinorthis sp. *cf. D. quadriplicata* Willard	×	.....
Dinorthis sp. *cf. D. atavoides* Willard	×	.....
Doloroides sp.	.....	×
Fascifera sp.	.....	×
Glyptorthis sp. *cf. G. bellarugosa* (Conrad)	.....	×
Öpikina sp. *cf. Ö. champlainensis* (Raymond)	.....	×
Öpikina magna (Butts)	×	×
Öpikina minnesotensis (Winchell)	×	×
Öpikina sp.	.....	×
Multicostella magna Schuchert & Cooper	×	.....
Strophomena amploides Butts	×	×
Strophomena medialis Butts	×	×
Strophomena sp.	×	×
Sowerbyella aequistriatus Willard	×	×
Orthoceras sp.	.....	×

1. West of road, south of Glass Store, Va.
2. Along road 2½ miles west of Stickleyville, Va.

Paleontology.—The "Ottosee" of Lee County has few fossils. The most prolific zone is the *Dinorthis* bed in Zone 6 of the Glass Store section. These beds can be traced along the strike to Stickleyville, where they pass into yellow shale with incorporated nodules of limestone, a lithology like that of the upper "Ottosee" of Rye Cove. The fauna collected from the *Dinorthis* bed is listed in Table 3.

The "Ottosee" at Rye Cove consists of two major facies, a lower, brown, crystalline "Holston" lithology and an upper yellow shale and nodular limestone facies. The lower "Ottosee" has *Girvanella*, *Gonioceras*, *Maclurites*, *Carabocrinus* plates, and a prominent zone of associated *Nidulites* and *Sowerbyella aequistriatus*. The lower "Ottosee" of the Glass Store section and Dickerson Ford has abundant *Camarotoechia; Tetradium, Gonioceras, Lophospira,* and *Girvanella.* The upper shaly "Ottosee" of Rye Cove has a large fauna in which the forms listed in Table 4 are abundant.

Fossils are not abundant in the "Ottosee" of central Lee County, where many

of the lithologic zones of southeastern sections have passed into dove-gray calcilutites. A small faunule collected along the road at Walnut Hill School west of Gibson Station Post Office is listed in Table 5.

Dinorthis beds (Zone 6) of the Glass Store section, which seem to correspond to the yellow shale and red mud rock of central Lee County can be traced southeastward into yellow shales and limestones which are faunally and lithologi-

TABLE 4

FAUNULE FROM UPPER SHALY "OTTOSEE" OF RYE COVE

Receptaculites sp.

Batostoma sevieri Bassler
"Chasmatopora" (*Subretopora*) sp.
Cornotrypa inflata (Hall)
Escharopora sp.
Mesotrypa sp.
Pachydictya sp.

Campylorthis deflecta (?) Ulrich & Cooper
Dinorthis transversa Willard
Glyptorthis sp. *cf. G. bellarugosa* (Conrad)
Hesperorthis tricenaria (Conrad)
Lingula sp.
Mimella superba Butts
Multicostella sp. *cf. M. platys* Billings
Leptaena sp. *cf. L. palustris* Willard

Öpikina magna (Butts)
Schizambon cuneatus Willard
Sowerbyella aequistriatus Willard
Strophomena amploides Butts

Bucania sp.

Gonioceras sp.

Bumastus sp.
Illaenus sp.
Illaenus sp. *cf. I. fieldi* Raymond

TABLE 5

FAUNULE FROM "OTTOSEE," WALNUT HILL SCHOOL

Tetradium cellulosum (Hall)

Batostoma sevieri Bassler
Escharopora ramosa Ulrich

Camarotoechia plena (Hall)
Camarotoechia sp.
Ancistrorhyncha sp.
Hesperorthis tricenaria (Conrad)
Glyptorthis sp. *cf. G. bellarugosa* (Conrad)
Öpikina sp.

Strophomena sp.
Zygospira recurvirostris (Hall)

Helicotoma sp.
Lophospira sp.

Gonioceras sp.

Leperditia fabulites (Conrad)
Calliops sp. *cf. C. callicephalus* (Hall)

Correlation.—The lower 250–300 feet of the Lee County "Lowville of Butts" is believed equivalent to the "Ottosee" of Rye Cove. This conclusion is based on the following facts: (1) the "Ottosee"of Lee County is stratigraphically similar to the "Ottosee" of Rye Cove; both units overlie the cherty "Lenoir" and are overlain by dove-gray limestones with *Stromatocerium* and *Cryptophragmus;* (2) the cally like the upper shaly "Ottosee" o Rye Cove; and (3) the brown, crystalli limestone in the lower "Ottosee" of L County sections resembles that in th lower "Ottosee" of Rye Cove.

"LOWER MOCCASIN" FORMATION—(ZONES 7–12)

The "Lower Moccasin" includes 25 300 feet of dove-gray limestone (Tab 6). A prominent zone of *Stromatocerium*

TABLE 6

SUBDIVISIONS OF THE "LOWER MOCCASIN" FORMATION

"MOCCASIN" FORMATION

"LOWER MOCCASIN" FORMATION

Zone

12. *Yellow-shaly limestone:* This zone includes 25 feet of thin-bedded, shaly limestone with abundant *Rhinidictya nicholsoni*, *Escharopora subrecta*, and *Zygospira recurvirostris*. Well exposed in the vicinity of Harrogate, Tennessee, especially in the railroad cut east of Harrogate.

11. *Cryptophragmus and Camarocladia limestones:* Approximately 100 feet of dove-gray, dense limestone with occasional thin beds of gray, crystalline limestone. Characterized by a zone of *Camarocladia* near the base and *Cryptophragmus antiquatus* throughout. In southeastern Lee County a prominent zone of black chert is at the top.

10. *Gray, crystalline limestone:* Consists of from 3 to 8 feet of coarse, fragmental limestone. Best developed at the base of the quarries southeast of Harrogate, Tennessee.

9. *Hesperorthis beds:* Includes a maximum thickness of 60 feet of dove-gray, dense, platy limestone with a prominent zone of *Hesperorthis tricenaria* and associated *Öpikina* sp. 10 feet above the base. Well developed throughout central Lee County where it invariably forms a prominent marker above the *Stromatocerium rugosum* beds.

8. *Stromatocerium beds: Stromatocerium rugosum* forms a prominent zone throughout Lee County, ranging in thickness from a few inches to a maximum of 20 feet west of Harrogate, Tennessee. This zone is persistent, mappable, and is identifiable in all the Lee County sections and at Rye Cove in Scott County, Virginia.

7. *Dove-gray calcilutite:* Dove-gray, dense, platy limestones. Locally, as at Glass Store, are thin beds of crystalline limestone. Marked at the top by a prominent zone of nodular black chert. Average thickness about 60 feet.

"OTTOSEE" FORMATION

rugosum is 65 feet above the base, and a one of associated *Hesperorthis tricenaria* nd *Öpikina* sp. is 10 feet higher. Beginning 125 feet above the base is a 100-foot zone (minimum) of dense to medium crystalline limestone having *Camarocladia* near the base and *Cryptophragmus antiquatus* throughout. At Harrogate, Tennessee, 25 feet of shaly limestone (Zone 12) with *Rhinidictya* and *Zygospira* overlie the *Cryptophragmus* beds; these shaly strata were not recognized elsewhere. The *Cryptophragmus* zone is about 100 feet in central Lee County; it thickens southeastward. A prominent zone of black chert often forms the top of this zone.

Paleontology.—The "Lower Moccasin" has a number of fossils in addition to those mentioned above. The forms listed in Table 7 were identified.

Correlation.—The strata referred to as "Lower Moccasin" in Lee County can be correlated with the "Lower Moccasin" of Rye Cove on lithological and faunal bases. At Rye Cove, *Stromatocerium* occurs 85 feet above the upper shaly "Ottosee" and *Cryptophragmus* is higher in the section. Use of the term "Lower Moccasin" is undesirable except for correlation purposes; according to Cooper,[24] these beds were not included in the original definition of the Moccasin formation but are actually older than the true Moccasin. New terminology is applied on a later page.

Good exposures of the "Ottosee" and "Lower Moccasin" are in southeastern Lee County, where several sections have been measured. The first section is south of Wallen Creek along the highway about $5\frac{1}{2}$ miles south of Jonesville. This is shown in Table 8.

In summary, the Glass Store section shows several significant features. There is predominance of gray, sublithologic limestone (Zone 3) in the lower part over-

[24] "Moccasin Formation in Southwestern Virginia" (abstr.), *Bull. Geol. Soc. Amer.*, Vol. LIII (1942), p. 1799.

TABLE 7

FAUNULE FROM "LOWER MOCCASIN" OF LEE COUNTY*

Camarocladia sp.
Cryptophragmus antiquatus Raymond

Stromatocerium rugosum Hall

Tetradium cellulosum (Hall)

Batostoma magnapora Ulrich
Batostoma sp.
"*Chasmatopora*" (*Subretopora*) sp. *cf. C. sublaxa* (Ulrich)
Escharopora sp.
Escharopora confluens Ulrich
Escharopora subrecta (Ulrich)
Rhinidictya nicholsoni Ulrich

Ancistrorhyncha sp.
Camarotoechia plena Hall
Fascifera sp.
Hesperorthis tricenaria (Conrad)
Öpikina sp. *cf. Ö. minnesotensis* (Winchell)
Öpikina sp. *cf. Ö. transitionalis* (Okulitch)
Pionodema subaequata (Conrad)
Zygospira recurvirostris (Hall)

Lophospira oweni Ulrich & Scofield
Liospira sp.
Trochonema sp.

Cycloceras sp.
Orthoceras multicameratum Emmons

Illeanus sp.
Trilobite fragments

Leperditia fabulites (Conrad)

* Collections from quarry east of Harrogate, Tenn., and second quarry northeast of Shawnee, Tenn., on Lee County line.

TABLE 8

SECTION AT GLASS STORE, SOUTH OF WALLEN CREEK

FORMATIONAL DESCRIPTION	THICKNESS IN FEET—	
	Of Unit	To Base of Formation
"Lower Moccasin":		
Cover with dove-gray, platy limestone with zone of black chert at top; *Cryptophragmus* zone	120.0	296.0
Dove-gray, dense, platy limestone	5.0	176.0
Cover	100.0	171.0
Cover with dove-gray, dense, thick-bedded limestone with nodular black chert; *Stromatocerium* in upper beds	43.5	71.0
Gray-brown, medium crystalline, thick-bedded limestone with *Gonioceras*	10.5	27.5
Brown, fine-textured, argillaceous limestone	17.0	17.0
"Ottosee":		
Yellow, argillaceous, nodular-weathering limestone with *Dinorthis*, *Öpikina*, *Strophomena*, *Sowerbyella*, others	26.5	301.0
Cover with beds of crystalline limestone	48.0	274.5
Brown, medium-crystalline limestone, weathers to thin, wavy beds	26.5	226.5
Brown, coarsely crystalline, friable limestone with large *Camarotoechia*	19.0	200.0
Gray, thick-bedded calcilutite	72.0	187.0
Cover, immediately south of creek	115.0	115.0
"Lenoir":		
Brown, dense, massive, cherty limestone		

lain by crystalline limestones (Zones 4 and 5), with abundant large *Camarotoechia* near the base. Higher in the section are the fossiliferous, shaly, nodular-weathering *Dinorthis* beds (Zone 6); these are regarded as the top of the "Ottosee." Seventy feet above is a conspicuous black chert bed with a persistent ledge of *Stromatocerium rugosum* at the top (Zones 7 and 8). Higher on the hillside, *Cryptophragmus* (Zone 11) is abundant.

TABLE 9

SECTION AT DICKERSON FORD, NORTH OF POWELL RIVER

Formational Description	Thickness in Feet— Of Unit	To Base of Formation
"Lower Moccasin":		
Dove-gray, dense limestone with *Cryptophragmus*, weathered outlines of brachiopods and gastropods	106.0	280.3
Cover with ledges of dove-gray, dense limestone	15.9	174.3
Cover with beds of finely crystalline limestone	13.8	158.4
Cover with beds of dove-gray, dense, platy limestone	58.3	144.6
Cover with thin beds of dove-gray limestone carrying *Stromatocerium*	45.0	86.3
Dove-gray, dense, platy limestone	26.5	41.3
Gray-brown, dense to finely crystalline limestone	14.8	14.8
"Ottosee":		
Cover with thin beds of yellow, shaly limestone	19.1	324.0
Brown, medium-crystalline, thin-bedded limestone; forms top of quarry	33.4	304.9
Brown, dense, thick-bedded limestone with *Gonioceras*, outlines of brachiopods and gastropods	13.3	271.5
Cover with ledges of crystalline limestone	19.1	258.2
Brown, crystalline, nodular-weathering limestone with *Girvanella*, *Gonioceras*, trilobite fragments	16.4	239.1
Gray, sublithographic, massive-bedded, limestone with calcite stringers; surface etched and covered with outlines of *Lophospira* sp.	72.1	222.7
Yellow, shaly limestone grading into red, calcareous shale at the top	10.1	150.6
Dove-gray, dense, medium-bedded limestone, weathers thin-bedded; zone of *Tetradium* near base	61.5	140.5
Cover with ledges of thin-bedded limestone	63.6	79.0
Brown, shaly limestone in ledges separated by cover; lower beds weather to irregular, cobbly surface	15.4	15.4
"Lenoir":		
Brown, dense, massive, cherty limestone	Not measured	

A second section, located on the north side of the Powell River about 5 miles south of Jonesville, is shown in Table 9. This section (Dickerson Ford) compares closely with the Glass Store section. The red shale (Zone 2) roughly 150 feet above the base is not exposed at Glass Store. Beds of the *Dinorthis* horizon (Zone 6) are poorly exposed at Dickerson Ford, where they are represented by beds of shaly limestone. The *Stromatocerium* zone is about 250 feet above the red shale and approximately 70 feet above the shaly, nodular-weathering limestone of Zone 6. A 100-foot zone of *Cryptophragmus* is about 75 feet above the *Stromatocerium* bed.

A third section is exposed along the limb of the Powell Valley anticline south of Deep Spring School on the northwest slope of Wallen Ridge. Inasmuch as cover conceals the contact between the

"Ottosee" and "Lower Moccasin," it is difficult to divide the section. The brown, crystalline, *Camarotoechia* beds (Zone 4) are well exposed, and a 100-foot zone of *Cryptophragmus* is near the top.

MOCCASIN FORMATION—(ZONES 13 AND 14)

The Moccasin includes two distinct and well-defined facies:

Zone 14. *Dove-gray, laminated limestone:* This zone includes a maximum of 135 feet of dove-gray, thick-bedded laminated limestone with several thin metabentonites near the top and a 25 foot cherty zone about 30 feet above the base. It is best exposed at the Hagan railroad siding, where the entire thickness can be seen. It is partially exposed on Wallen Ridge near Deep Spring School.

Zone 13. *Yellow-green mud rock:* Comprises a maximum of 175 feet of yellow-green calcareous unfossiliferous mud rock. It is generally nonresistant and poorly exposed. The lower beds can be seen near the top of the Wheeler quarry northeast of Gibson Station, the upper beds at Hagan railroad siding, and median ledges on the northwest slope of Wallen Ridge near Deep Spring School.

The Moccasin overlies the "Lower Moccasin" with no evidence of unconformity. It is overlain by the Eggleston formation; a metabentonite zone separates the two formations.

Paleontology and correlation.—Fossils were not collected from this horizon. The beds seem to correspond lithologically to the Moccasin formation of southwestern Virginia.

EGGLESTON FORMATION—(ZONE 15)

The Eggleston is an assemblage of yellow mud rock, dove-gray limestone, and thick metabentonites (Fig. 4). The formation is approximately 150 feet thick in central Lee County; it thickens southeastward to about 175 feet at Wallen Ridge, south of Jonesville. The thickness seems uniform along the strike. A thin metabentonite, exposed at Hagan, Virginia, separates the Eggleston from the underlying Moccasin. A pair of thick metabentonites (3–4 feet) with their associated basal chert zones, separated by 40–50 feet of limestone and yellow, calcite-flecked mud rock, are near the top. The interval between these metabentonites is relatively constant; 40 feet at Hagan, Virginia; 40 feet at Harrogate, Tennessee; 46 feet at Turkey Cove, Virginia; and 49 feet at Wallen Ridge south of Jonesville. The two thick metabentonites seem to correspond to metabentonites $V4$ and $V7$ of the Rosenkrans classification. Precise correlation of the lower metabentonite has not been made; it seems to correspond to metabentonite $V3$ in the lower Eggleston of southwestern Virginia.

The uppermost metabentonite ($V7$) is overlain by 10–15 feet of alternating shale and limestone with intercalated mud rock (Zone 16). The term "cuneiform" has been applied to these beds because of the peculiar right-angle fracture of some of the limestone beds. At Harrogate, Tennessee, and Turkey Cove, Virginia, the thin limestones of the "cuneiform" beds pass upward into a thin, friable calcarenite which forms the base of the crystalline "Trenton" limestones. Inasmuch as these beds are transitional, it is difficult to say whether they should be included in the Eggleston or in the overlying formation. Rosenkrans[25] included the "cuneiform" beds in the "Trenton," drawing his boundary 2 feet below the upper metabentonite, $V7$, where he believed a hiatus occurs. The accordant thickness of beds between the two thick metabentonites in Lee County offers no indication of a hiatus at this horizon. The presence of *Sowerbyella curdsvillensis* and *Dalmanella fertilis* serves to tie these beds with the overlying fossiliferous "Trenton" limestone. In

[25] P. 96 of ftn. 9 (1936).

central Kentucky, the crystalline, *Sowerbyella*-bearing Curdsville limestone lies directly on a thick (3–4 foot) metabentonite which seems to correspond to metabentonite *V7*. It appears best, therefore, to draw the top of the Eggleston at the top of the upper metabentonite and include the "cuneiform" beds in the overlying formation.

Paleontology.—The Eggleston has yielded a number of fossils. The thin, shaly limestones in the lower part carry a fauna with *Rhinidictya* and *Escharopora*. *Tetradium* is common throughout. A limestone above metabentonite *V4* has abundant *Strophomena* and *Öpikina*, while numerous pelecypods and cephalopods are found in the nodular shales and mud rock between the upper metabentonites. The faunules collected from the Eggleston are shown in Table 10.

Correlation.—This is the Eggleston formation or Eggleston facies of authors. The Eggleston was defined by Mathews in 1934 to include "the beds of upper Black River age that are younger than the upper red Moccasin and older than the Trenton." The Eggleston forms a "transition zone" between the Moccasin formation and the limestones of the "Trenton." In areas to the southeast, Rosenkrans[26] has concluded that, since the upper and lower limits of the Eggleston as found in the type locality vary from place to place, the Eggleston is merely a facies of the Moccasin. This paper does not intend to entertain the status of the Eggleston, but, because of its distinctive characteristics in Lee County, it is given equal rank with Moccasin and others. Metabentonites *V7* and *V4* are believed to correspond to the Mud Cave clay and the Pencil Cave clay of the Carters formation in Tennessee.

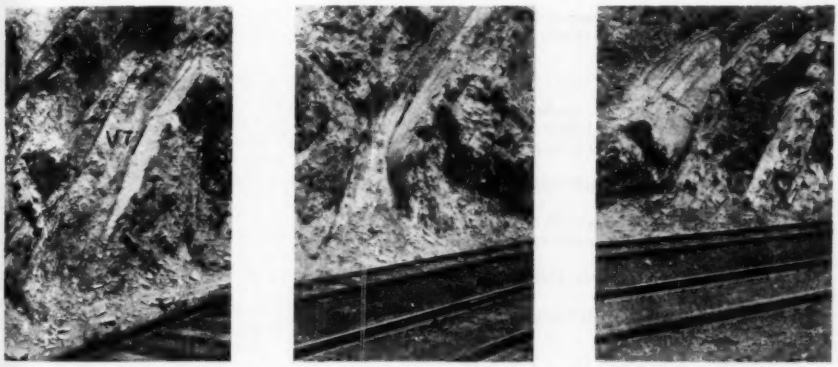

FIG. 4.—Eggleston metabentonites at Hagan, Virginia. *Left:* Upper metabentonite *V7* lying on 4 inches of black, rippled chert. *Center:* Metabentonite *V4:* note changes in thickness introduced by folding. *Right:* Lower metabentonite *V3* (?). Note small fault in center of picture repeating 8 feet of beds.

The Eggleston is nicely exposed at Turkey Cove, Hagan, and on Wallen Ridge south of Jonesville in Virginia, and along the railroad east of Harrogate, Tennessee. Partial sections near Turkey Cove have been described by Bates,[27] and the Wallen Ridge section is given by Rosencrans.[28] The most complete section

[26] *Ibid.*, p. 92.

[27] Pp. 50–51 of ftn. 11 (1939).

[28] Pp. 110–11 of ftn. 9 (1936).

is at Hagan, Virginia, where a continuous section of strata from upper Moccasin to "Catheys-Cannon" can be seen (Table 11).

beds. Very fossiliferous with *Sowerbyella curdsvillensis*, *Dinorthis pectinella*, and *Dalmanella fertilis*. Average thickness 30 feet. Well exposed at Harrogate, Tennessee, and Hagan, Virginia.

TABLE 10

FAUNULES FROM THE EGGLESTON OF LEE COUNTY

	Localities		
	1	2	3
Stromatocerium sp. (rare)			
Lambeophyllum profundum (Conrad)		×	
Tetradium cellulosum (Hall)	×	×	×
Arthroclema sp.			×
Batostoma sp.			×
Escharopora sp. *cf. E. confluens* Ulrich		×	×
Escharopora subrecta Ulrich		×	×
Rhinidictya nicholsoni Ulrich	×	×	×
Doleroides sp. *cf. D. gibbosus* (Billings)			×
Opikina sp.		×	
Opikina sp. *cf. Ö. minnesotensis* (Winchell)		×	
Opikina sp. *cf. Ö. transitionalis* (Okulitch)	×		×
Strophomena sp.			×
Zygospira recurvirostris (Hall)	×	×	×
Cyrtodonta sp. *cf. C. huronensis* Billings		×	×
Helicotoma sp.		×	×
Lophospira oweni Ulrich and Scofield		×	
Lophospira sp.		×	×
Cameroceras sp.		×	
Cycloceras sp.		×	
Endoceras sp.		×	
Aparchites sp.			×
Eurychilina subradiata Ulrich			×
Primitiella sp. (?)			×
Leperditia fabulites (Conrad)	×	×	×
Calliops sp. *cf. C. callicephalus* (Hall)		×	
Eomonorachus sp.			×
Illaenus sp.			×

1. East side of road, Wallen Ridge south of Jonesville, Va.
2. Along road 2½ miles east of Cumberland Gap in Lee County, Va.
3. Along road through Turkey Cove, Va.

CURDSVILLE FORMATION (ZONES 16–17)

The Curdsville, as here designated, includes two zones:

Zone 17. *Sowerbyella-bearing limestone:* Blue-gray, coarsely crystalline limestone in 2-10 inch

Zone 16. *Upper "cuneiform" beds:* A se quence of thin limestones and shale overlying metabentonite *V7*. Average thickness 10–1 feet. Grade upward into a friable calcarenit which forms the base of Zone 17. Well expose at Turkey Cove and Hagan, Virginia, an Harrogate, Tennessee.

TABLE 11

SECTION ALONG RAILROAD SIDING, HAGAN, VIRGINIA

FORMATIONAL DESCRIPTION	THICKNESS IN FEET—	
	Of Unit	To Base of Formation
"Catheys-Cannon":		
Blue-gray, medium-crystalline limestone; fossiliferous	230.0	230.0
Hermitage:		
Cover with shale slump	25.0	71.4
Yellow, plastic metabentonite	1.0	46.4
Yellow-brown, platy, fossiliferous shale with *Dalmanella*	10.0	45.4
Blue-gray, medium-crystalline limestone in 2–4 inch beds separated by thin, gray shales; *Sinuites*, *Dalmanella*, *Sowerbyella*	35.0	35.4
Blue, plastic metabentonite	0.4	0.4
Curdsville:		
Blue-gray, coarse-textured limestone in 2–10 inch beds with *Sowerbyella*, *Dinorthis*, *Dalmanella*	30.0	40.2
Gray, dense limestone in thin, nodular layers separated by shale	5.0	10.2
Gray, dense, thick-bedded limestone	3.9	5.2
Yellow, calcareous mud rock	0.8	1.3
Dove-gray, dense limestone in thin beds separated by gray shale	0.5	0.5
Eggleston:		
Yellow-green, micaceous metabentonite	2.0	147.1
Gray, soft, micaceous metabentonite	1.0	145.1
Gray-brown, hard metabentonite (V_7)	1.0	144.1
Black, rippled chert	0.5	143.1
Dove-gray, dense limestone	6.0	142.6
Yellow, calcareous mud rock	18.0	136.6
Dove-gray, dense limestone	14.0	118.6
Yellow-green metabentonite (V_4)	3.0	104.6
Black, rippled chert	0.3	101.6
Dove-gray, dense, platy limestone	38.0	101.3
Gray, bentonitic (?) shale	0.5	63.3
Dove-gray, dense, shaly limestone	20.0	62.8
Blue-gray, structureless mud rock	34.0	42.8
Dove-gray, dense, thick-bedded limestone (repeated by small fault)	8.0	8.8
Gray, fine-textured shale	0.3	0.8
Blue-gray, micaceous metabentonite	0.5	0.5
Moccasin:		
Dove-gray, dense limestone	4.0	147.4
Green, shaly metabentonite	0.1	143.4
Dove-gray, dense limestone	20.0	143.3
Blue-gray, shaly metabentonite	0.3	123.3
Dove-gray, dense limestone	30.0	123.0
Dove-gray, dense, laminated limestone with nodular chert	78.0	93.0
Brown-green, massive, mud rock	15.0	15.0
Base of exposure:		

The Curdsville is limited at the base by a 3- to 4-foot metabentonite (*V7*) and is separated from the overlying formation by a varying thickness of blue, hard, shaly metabentonite.

Paleontology.—The Curdsville is highly fossiliferous and is characterized by the association of *Sowerbyella curdsvillensis*, *Dinorthis pectinella*, and *Dalmanella fertilis*. The "cuneiform" beds are sparingly fossiliferous, but slabs with *Sowerbyella* and *Dalmanella* have been collected.

TABLE 12

FAUNULES FROM THE CURDSVILLE OF SOUTHWESTERN VIRGINIA

	Localities		
	1	2	3
"Chasmatopora" (Subretopora) sp.	×	....	×
Hallopora sp.	....	....	×
Prasopora sp.	....	×	×
Rhinidictya sp.	....	×	....
Dalmanella fertilis Bassler	×	×	×
Dinorthis pectinella (Emmons)	×	×	×
Hesperorthis tricenaria Conrad	×	×	×
Rafinesquina alternata	×	....	×
Sowerbyella curdsvillensis (Foerste)	×	×	×
Zygospira recurvirostris Hall	....	....	×
Cyrtolites ornatus Conrad	....	....	×

1. Railroad cut southeast of Harrogate, Tenn.
2. Railroad siding east of Hagan, Va.
3. East side of Big A Mountain, ¼ mile north of Fullers Corner, Russell County, Va. (collected by Marshall Kay).

Correlation.—The fauna and lithology of this formation resemble those of the Curdsville formation in areas to the north and west. The Curdsville apparently has not been recognized in the northwest belt of the Appalachian Valley, although fossil lists invariably carry Curdsville fauna. The widespread nature of the Curdsville in southwestern Virginia is indicated by its presence as far north as Big A Mountain near Honaker, Virginia. A faunule collected from the east side of Big A Mountain is compared in Table 12 with that from Lee County, Virginia.

Good exposures of the Curdsville are at Harrogate, Tennessee, Hagan, Virginia, and Wallen Ridge south of Jonesville, Virginia. It was not recognized by earlier workers in Wise County,[29] but its presence as far northeast as Big A Mountain, Honaker, Virginia, indicates that its deposition was not limited to the Lee County area. The section at Hagan, Virginia, has been included in Table 11; a section at Harrogate, Tennessee, is shown in Table 13.

HERMITAGE FORMATION (ZONES 18–20)

The Hermitage consists of the following:

Zone 20. *Yellow calcareous shale:* Includes a maximum of 30 feet of yellow, calcareous shale with thin beds of fossiliferous limestone carrying abundant *Dalmanella*. A 12-inch bed of soft, yellow, metabentonite is 10 feet above the base. These beds are nonresistant and yield readily to slumping.

Zone 19. *Gray limestone with Dalmanella:* Gray, medium-crystalline, thin to medium-bedded limestone with thin shale partings. Marked by the abundance of *Dalmanella fertilis*. Thickness 15–20 feet. Passes upward into a massive ledge of yellow, hard, calcareous shale which forms the base of Zone 20.

Zone 18. *Sinuites Beds:* Comprises 10–15 feet of gray, fine-textured limestone in thin beds separated by thin layers of gray, siliceous shale. Characterized by an abundance of *Sinuites cancellatus* and *Dalmanella fertilis*.

The Hermitage is separated from the underlying Curdsville by a bed of hard, blue metabentonite. Contact with the overlying "Catheys-Cannon" is not clearly shown in the limited exposures examined. The Hermitage is exposed along the road 2½ miles east of Cumberland Gap, Tennessee; along the railroad at Harrogate, Tennessee; and along the side

[29] Stose *et al.*, pp. 22–28 of ftn. 10 (1923).

ing at Hagan, Virginia (see Tables 11 and 13).

Paleontology.—The Hermitage is very fossiliferous, with a zone of *Sinuites* near the base and *Dalmanella* common throughout. The fauna collected from the Lee County exposures is shown in Table 14.

Correlation.—Lithologically and faunally these beds correspond to the post-Curdsville portion of the Hermitage of Tennessee. According to C. W. Wilson, Jr.,[30] the lower part of the Hermitage formation in the central basin of Tennessee can be separated from the overlying part of the Hermitage as a distinct lithologic and faunal unit which he considers to be of Curdsville age. This not only serves to strengthen the correlation

TABLE 13

SECTION ALONG RAILROAD EAST OF HARROGATE, TENNESSEE

Formational Description	Thickness in Feet—	
	Of Unit	To Base of Formation
Hermitage:		
Yellow to reddish-brown shale	7.6	48.7
Yellow, crumbly metabentonite	0.6	41.1
Yellow, thin-bedded shale	2.5	40.5
Yellow-drab, calcareous shale in one massive bed, breaks to thin yellow shale with intercalated beds of fossiliferous limestone	6.0	38.0
Blue-gray, medium-crystalline limestone, thin to medium bedded with thin shale partings; fossiliferous with *Dalmanella*	15.0	32.0
Gray, fine-textured, thin-bedded limestone separated by gray, siliceous shale; abundant *Sinuites*	15.0	17.0
Blue, hard, shaly metabentonite, breaks to angular fragments	2.0	2.0
Curdsville:		
Blue-gray, medium-crystalline limestone in medium beds with thin shale partings; with *Dinorthis*, *Sowerbyella*, and *Dalmanella*	10.0	45.6
Blue, fissile shale	0.5	35.6
Blue-gray, crystalline limestone in medium beds, highly fossiliferous with *Dinorthis* and *Sowerbyella*	25.5	35.1
Gray to brown, dense limestone passing upward into a brown, friable calcarenite which forms the base of overlying limestone	3.0	9.6
Dove-gray, dense limestone in nodular beds separated by blue-gray shale	1.2	6.6
Dove-gray, dense limestone in medium beds, weathers shaly	4.2	5.4
Drab-green, hard, angular shale	1.2	1.2
Eggleston:		
Gray-green, crumbly metabentonite with abundant biotite flakes (V_7)	3.0	54.0
Black chert	0.3	51.0
Brown, dense, platy limestone with *Leperditia* and *Camarotoechia*	3.2	50.7
Yellow-blue, calcareous mud rock	35.0	47.5
Dove-gray, dense, platy limestone	1.3	12.5
Yellow, micaceous metabentonite (V_4)	3.0	11.2
Black chert	0.2	8.2
Dove-gray, dense limestone	8.0	8.0
Base of exposure:		

[30] "Curdsville Limestone Zone of Hermitage in Central Tennessee" (abstr.), *Bull. Geol. Soc. Amer.*, Vol. XLIX (1938), p. 1923.

of the Virginia and Tennessee sections but emphasizes the widespread nature of the Curdsville formation in the Appalachian Valley.

OVERLYING ROCKS

The "Catheys-Cannon" consists of blue-gray, granular, even-bedded, fossiliferous limestone with a maximum thickness of about 500 feet. No detailed study was made, but casual examination indicated that any division in Lee County should be made on faunal rather than on lithological criteria. Two formations, the Catheys and Cannon, have been recognized in Wise County,[31] and sections have been described in the Wise County report. Good exposures are rare in Lee County, but a continuous sequence of 230 feet is well shown at Hagan, Virginia.

TABLE 14

FAUNULES FROM THE HERMITAGE OF LEE COUNTY

	Localities		
	1	2	3
Hallopora sp.	×	....	×
Prasopora sp.	×	....	×
Prasopora falesi Hall.	×	....	×
Dalmanella fertilis Bassler	×	×	×
Hesperorthis tricenaria (Conrad)	....	×	....
Heterorthis clytie Hall	....	×	....
Rafinesquina hermitagensis Bassler	×	×	×
Rhynchotrema increbescens (Hall)	×	×	×
Sinuites cancellatus Hall	×	....	×
Modiolodon sp.	×	×	....
Calliops sp.	....	×	....
Crinoid stems	....	×	....

1. Railroad cut southeast of Harrogate, Tenn.
2. Along road 2½ miles east of Cumberland Gap, Tenn.
3. Railroad siding, Hagan, Va.

APPLICATION OF THE COOPER AND PROUTY TERMINOLOGY TO THE LEE COUNTY SECTION

Much of the terminology proposed by Cooper and Prouty[32] for the Middle Ordovician of Tazewell County, Virginia, can be applied to the Lee County section. Several of the zones of the Tazewell County classification have not been recognized in Lee County; they may be missing, or their identity is lost as they pass into calcilutites.

The "Murfreesboro" of Lee County corresponds to the Blackford member of the Cliffield formation which includes Zones 1, 2, and 3 of the Tazewell section. The Blackford lies unconformably on the Beekmantown dolomite; a prominent bed of basal clastics is present. The "Mosheim" of Lee County is the first calcilutite (Zone 4), or the Five Oaks member of the Cliffield formation, and the "Lenoir" is probably, at least in part, equivalent to the Lincolnshire member. The brown calcilutite (Zone 1 of the "Ottosee" of Lee County) is stratigraphically similar to the Ward Cove limestone, while the gray calcilutite (Zone 3 of Lee County) with the numerous *Lophospira* seems to correspond to the *Lophospira* beds and the second calcilutite of the Peery limestone. The *Camarotoechia*-bearing calcarenite and the overlying *Gonioceras* beds probably correspond to the second coarse-grained limestone of the Tazewell section (lower Benbolt), while the shaly, nodular *Dinorthis* beds of the Glass Store section and the upper shaly part of the "Ottosee" of Rye Cove are considered equivalent to the upper Benbolt. The Gratton limestone of Tazewell County is then represented by a dove-gray calcilutite (Zone 7) in Lee County. Zones 8, 9, and 10 of Lee County can be correlated with the

[31] Stose *et al.*, pp. 22–28 of ftn. 10 (1923).

[32] P. 884, Fig. 3 of ftn. 3 (1943).

Wardell formation of Tazewell County, which includes the *Stromatocerium rugosum* beds at its base. Strata equivalent to the Bowen formation were not recognized in Lee County. The *Cryptophragmus* and *Camarocladia* beds which form the upper part of the "Lower Moccasin" of Lee County are correlated with the Witten limestone of Tazewell County.

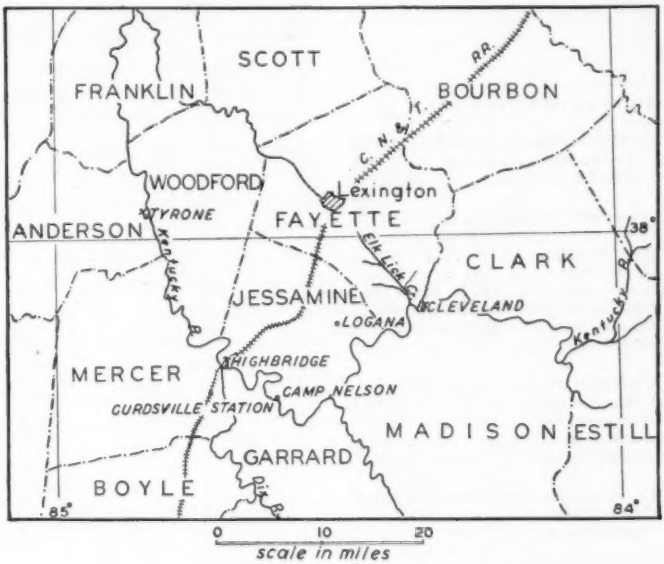

FIG. 5.—Map showing location of sections in central Kentucky

The Moccasin and Eggleston formations of Lee County are believed to be the same as the Moccasin and Eggleston of Tazewell County, while the overlying Curdsville and Hermitage have been included in the Martinsburg shale of northern Virginia.

STRATIGRAPHY OF THE CENTRAL KENTUCKY SECTION

INTRODUCTION

Middle Ordovician formations are exposed along the bluffs of the Kentucky River south of Lexington, Kentucky. Two series have been recognized: the Highbridge series, including the Camp Nelson, Oregon, and Tyrone formations, and the Lexington series, including the Curdsville, Logana, Jessamine, Benson, Brannon, Woodburn, Perryville, and Cynthiana in ascending order. This paper is concerned primarily with five formations: Camp Nelson, Oregon, Tyrone, Curdsville, and Logana ("Hermitage"). All these formations have their type localities in the central Kentucky area (see Fig. 5). The name "Hermitage" has been borrowed from Tennessee by some to replace the earlier name "Logana."

STRATIGRAPHIC SEQUENCE

"HIGHBRIDGE SERIES"

CAMP NELSON FORMATION

The Camp Nelson was named for exposures along the Kentucky River, especially in the vicinity of Camp Nelson,

where approximately 315 feet is exposed above water level. The rock is largely of dense, dove-gray limestone with intercalated streaks of dolomitic material which give a mottled appearance on fresh surface and result in a honeycombed condition upon weathering. The lower 100 feet of exposed limestone is massively bedded and sparingly fossiliferous. The succeeding ledges are thinner bedded and locally contain shaly beds which weather to form deep recesses. The formation becomes increasingly shaly near the top, and locally, as at Highbridge, a 3-foot bed of blue, calcareous mud rock is at or near the top. The base of the Camp Nelson is not exposed, but well sections indicate a thickness of as much as 480 feet. It is overlain by the Oregon formation; the relation of these two formations will be discussed later.

TABLE 15

FAUNULES FROM THE CAMP NELSON FORMATION

	Locality		
	1	2	3
Tetradium cellulosum (Hall)	.....	×	.....
Escharopora sp. *cf. E. confluens* Ulrich	.....	×	.....
Mesotrypa sp.	×	×	×
Unidentified Bryozoa	×	×	×
Ancistrorhyncha sp.	×	×	×
Camarotoechia plena (Hall)	×	.....	×
Doleroides sp.	×	.....	×
Glyptorthis sp.	×	.....	×
Multicostella(?) sp. *aff. M. platys* (Billings)	×	.....	.....
Öpikina sp. *cf. Ö. minnesotensis* (Winchell)	×	×	×
Öpikina sp. *cf. Ö. transitionalis* (Okulitch)	×	.....	.....
Strophomena sp.	×	.....	.....
Cycloceras sp.	.....	.....	×
Gonioceras sp.	×	×	×
Helicotoma sp.	.....	×	.....
Liospira sp.	×	.....	.....
Lophospira sp.	×	.....	×
Cryptophragmus antiquatus Raymond	×	×	×
Camarocladia sp.	×	×	×
Tentaculites sp.	×	.....	×
Calliops sp.	×	.....	.....
Isotelus sp. (cephalon)	×	.....	.....
Leperditia fabulites (Conrad)	×	×	×
Cystid plates	.....	×	.....

1. Along north roadside above Camp Nelson bridge.
2. Shaly beds along north river bluff, Highbridge Park.
3. Along road north of Brooklyn Bridge.

Paleontology.—Fossils are not abundant in the Camp Nelson. The upper part contains scattered *Gonioceras* and *Maclurites*, while the shaly beds have a few species of brachiopods and other fossils. *Camarocladia* is common and *Cryptophragmus antiquatus* forms a prominent zone (65 feet or more) in the upper 90 feet. *Stromatocerium* occurs only sparing-

ly. The faunule collected by the writer is listed in Table 15.

OREGON FORMATION

The Oregon was named for exposures at Lock Number 6, near Oregon, in southern Woodford County, Kentucky, where it consists of 35 feet of heavy, even-bedded, highly magnesian, cream-colored dolomite. The rock is unfossiliferous and breaks with a conchoidal fracture. The Oregon overlies the Camp Nelson. A disconformity is suggested by local variations in the base of the Oregón. At Elk Lick Falls two heavy beds of cream, dolomitic limestone, prominently jointed, lie with sharp contact on the underlying Camp Nelson; at Highbridge a 3-foot bed of blue mud rock is near their contact; at other sections the limestones of the Camp Nelson type seem to grade into those of the Oregon type. The Oregon is overlain conformably by the Tyrone. A sequence of 8–10 feet of beds of the mixed Oregon and Tyrone types lies below the lowest metabentonite of the Tyrone.

TYRONE FORMATION

This is the "Birdseye" limestone of Linney. It was named for exposures near Tyrone, Anderson County, Kentucky, where about 75 feet is exposed. The Tyrone is largely of dove-gray limestone which breaks with a conchoidal fracture and exhibits on fresh surface, calcite facets which have suggested the name "Birdseye." The Tyrone has three metabentonites, two of which are very prominent. Associated with the two upper metabentonites are 3- to 4-inch beds of black chert formed at the contact with the subjacent limestone. The lowest metabentonite is at or near the base of the Tyrone. The second metabentonite is 55 feet above, while the third separates the Tyrone from the overlying Curdsville. The lower metabentonite varies in thickness from a thin clay seam to 18 inches; the second is typically from 30 inches to 3 feet; the upper varies from 3–4 feet. The metabentonites are white to green in color. The lower 55 feet of limestone is dove-gray, sublithographic, and weathers with a whitish surface.

TABLE 16

FAUNULES FROM THE TYRONE FORMATION

	Locality	
	1	2
Escharopora sp. *cf. E. confluens* Ulrich	×	×
Rhinidictya nicholsoni Ulrich	×	×
Batostoma sp.	×	×
Dermatostoma tyronensis Foerste	×	×
Tetradium cellulosum (Hall)	×	×
Tetradium sp. *cf. T. racemosum* Raymond	×	×
Strophomena sp. *aff. S. dignata* Fenton	×	×
Strophomena sp. *cf. S. plattinensis* Fenton	.....	×
Actinoceras sp.	.....	×
Endoceras sp.	.....	×
Helicotoma planula Salter	×	×
Hormotoma gracilis (Hall)	×	×
Lophospira oweni Ulrich and Scofield	×	×
Raphistoma denticulata Ulrich	.....	×
Sactoceras tyronensis Foerste	×	×
Bathyurus extans Hall	.....	×
Bathyurus spiniger Hall	×	.....
Drepanella crassinoda Ulrich	.....	×
Isochilina sp.	.....	×

1. Along Elk Lick Creek west of highway south of Lexington, Ky.
2. Kentucky Stone Quarry, Highbridge, Ky.

Conspicuous ledges carry a small fauna with numerous *Tetradium*. The 20 feet of limestone separating the two thick metabentonites always includes a few feet of yellow-green, calcite-flecked mud rock. The upper limestone beds have a small amount of nodular gray chert.

Paleontology.—The Tyrone is not very fossiliferous, although there are several conspicuous fossil horizons. The shaly layers in the lower 55 feet have a few

brachiopods and associated fossils; the black chert at the base of the second metabentonite is filled with silicified outlines of gastropods and cephalopods; the limestone above the second metabentonite carries numerous fossils; the mud rock in the upper 20 feet has *Rhinidictya* and *Zygospira*. The faunules collected from the Tyrone are shown in Table 16.

"LEXINGTON SERIES"

CURDSVILLE FORMATION

The Curdsville, named for exposures near Curdsville Station, Mercer County,

FIG. 6.—Typical cross-bedding in the basal Curdsville as shown in sections along the railroad south of Highbridge, Kentucky.

Kentucky, comprises 20 feet of gray, coarsely crystalline limestone with some nodular chert. The Curdsville lies with apparent conformity on the upper metabentonite of the Tyrone. The basal Curdsville is "rolled" and slightly chertified at the contact with the metabentonite. Two feet above the base, the crystalline limestones locally show cross-bedding, indicative of shallow-water deposition (Fig. 6). The upper beds typically weather to a red residual clay filled with nodules of white chert. A thin metabentonite has been recognized near the top of the Curdsville in some localities.[33]

[33] D. M. Young, "Bentonitic Clay Horizons and Associated Chert," *Univ. Ky. Research Club, Bull. 6* (1940), pp. 27–31.

The presence of a disconformity at the base of the Curdsville is not confirmed by present studies. The Curdsville, near the type locality, lies in direct contact with the thick metabentonite at the top of the Tyrone (Fig. 7). This metabentonite is persistent over a large area and can be

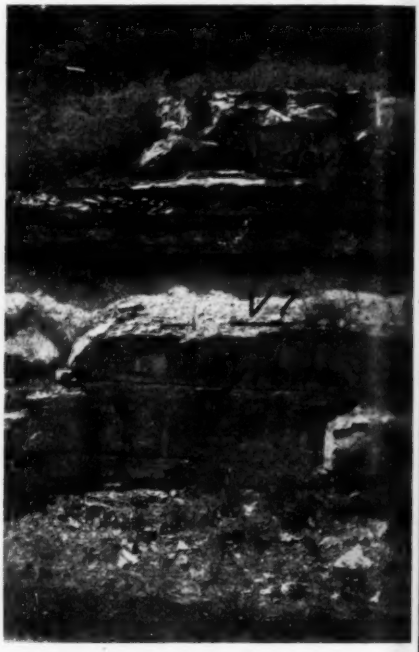

FIG. 7.—Curdsville limestone overlying the upper metabentonite in the Tyrone. Exposure 1½ miles south of Highbridge, Kentucky, along the railroad.

traced for considerable distance with little diminution in thickness. It seems impossible for an unconformity of any magnitude to exist at a metabentonite horizon without removal of the clay. Local reported absence of the clay with "welded" contact between the Curdsville and Tyrone can be attributed to agitation by wave action at or near wave base.

Paleontology.—The Curdsville is characterized by the association of *Sowerbyel-*

la curdsvillensis and *Dinorthis pectinella*. Fossils collected at the type locality are listed in Table 17.

LOGANA ("HERMITAGE") FORMATION

The name "Logana" was given by A. M. Miller[34] to 10 feet of argillaceous limestone and shale overlying the Curdsville and underlying the Hermitage. In 1906[35] the definition was expanded to include the beds between the Curdsville and Wilmore (Jessamine). Later, Foerste and Miller[36] stated that the Logana is the same as the Hermitage of Tennessee, and the name "Hermitage" was applied to 35 feet of beds of which the original Logana formed the basal 10 feet. Raymond[37] continued to use the name "Logana" for the 25–35 feet of clayey limestone and shale immediately above the Curdsville. Inasmuch as the Hermitage has its type locality in Tennessee and since, according to Wilson,[38] the Hermitage of central Tennessee may contain strata of Curdsville age, retention of the name "Logana" for strata immediately above the Curdsville of Kentucky is urged.

The Logana ("Hermitage") of Kentucky consists of 35 feet of gray limestone in thin beds separated by siliceous gray shales. The formation is abundantly fossiliferous and is marked by the association of *Dalmanella fertilis*, *Heterorthis clytie*, *Prasopora falesi*, *Rafinesquina hermitagensis*, and *Lophospira* sp. The lower 10 feet is more siliceous and thinner-bedded than the succeeding 25 feet. The Logana conformably overlies the Curdsville and underlies the Jessamine.

TABLE 17

FAUNULE FROM THE CURDSVILLE FORMATION

Columnaria halli Nicholson
Lambeophyllum profundum (Conrad)

Dinorthis pectinella (Emmons)
Hesperorthis tricenaria Conrad
Platystrophia extensa McEwan
Rafinesquina sp.
Rhynchotrema increbescens (Hall)
Sowerbyella curdsvillensis (Foerste)
Cyrtodonta sp.
Cyrtolites ornatus Conrad
Vanuxemi sp.

Bathyurus spiniger Hall

Crinoid stems

OVERLYING ROCKS

The Logana is overlain by the sequence Jessamine, Benson, Brannon, Woodburn, Perryville, and Cynthiana. These are of middle and upper Trenton age. No study was made of these units, and correlations are, of necessity, from other sources.

CORRELATION WITH THE LEE COUNTY SECTION

The *Cryptophragmus* beds of the upper Camp Nelson can be correlated with the *Cryptophragmus* beds of the "Lower Moccasin" of Lee County or the Witten formation of Tazewell County, Virginia. The Tyrone of Kentucky is like the Eggleston of Virginia; the two thick metabentonites near the top of the Tyrone seem to correspond to a pair near the top of the Eggleston. The two formations

[34] *Ky. Geol. Surv. Bull. 2* (1905), pp. 9, 19.

[35] A. F. Foerste, *Ky. Geol. Surv. Bull. 7* (1906); Miller, *Ohio Nat.*, Vol., VI (1906), pp. 447–48.

[36] Foerste and Miller, *Ky. Geol. Surv.*, Vol. I, Part I (4th ser., 1913).

[37] P. E. Raymond, "Trenton of Central Tennessee and Kentucky," *Bull. Geol. Soc. Amer.*, Vol. XXIII (1922), p. 573.

[38] P. 1923 of ftn. 29 (1938).

have a similar fossil assemblage, and they are lithologically similar—the limestones in the Eggleston are like those in the Tyrone, and the beds of calcite-flecked mud rock in the Tyrone resemble those in the Eggleston. Correlation of the Oregon is uncertain, since it is unfossiliferous. It seems conformable with the overlying Tyrone. The upper Moccasin of Virginia is conformable with the Eggleston. Hence, the Oregon and Moccasin are in part equivalent; they occupy the same stratigraphic position.

The Curdsville of Kentucky is lithologically, faunally, and stratigraphically like the strata referred to as Curdsville in Lee County. The "cuneiform" beds at the base of the crystalline limestone facies in Lee County are believed to be a deeper-water facies of the lower Curdsville.

The Logana ("Hermitage") of Kentucky is equivalent to the Hermitage of the Lee County section and can be correlated with the post-Curdsville portion of the Hermitage of Tennessee.

Correlation of the overlying rocks has not been attempted by the writer. The correlations that appear below are from previous literature. The Jessamine, which is the zone of *Prasopora simulatrix*, has not been recognized in central Tennessee. Inasmuch as the Jessamine is not sharply separated from either the underlying Logana or the overlying Benson in Kentucky, its identity in the Appalachian region may be obscured. The Benson has been correlated with the Bigby of Tennessee; in fact, the Bigby formation of Ulrich (Columbia folio) is regarded as including the Benson, Brannon, and Woodburn.[39] The Bigby has not been recognized in Virginia, but it has been suggested by R. E. Bassler[40] that the Bigby may pass laterally into the Cannon of Virginia and Tennessee. According to Wilson,[41] the Bigby and Cannon limestones are of contemporary age, the Bigby-Cannon unit being composed of several facies, with the Bigby facies thickest along the western part of the central basin and the Cannon facies thickest along the eastern part. The overlying Catheys would then seem to correspond to the Perryville and Cynthiana.

[39] A. F. McFarlan, "Paleontology of Kentucky," *Ky. Geol. Surv.*, Vol. XXXVI (6th ser., 1931), p. 50.

[40] "Stratigraphy of the Central Basin of Tennessee," *Tenn. Geol. Surv. Bull. 38* (1932), pp. 86–87.

[41] "The Bigby, Cannon, and Cathey Formations in Central Tennessee" (abstr.), *Tenn. Acad. Sci. Jour.*, Vol. XVI, No. 2 (1941), p. 256.

Convergence from Virginia to Kentucky

An interesting convergence pattern can be worked from Virginia to Kentucky, using the preceding correlations. The minimum thickness of the *Cryptophragmus* beds in Lee County (100 feet) thins to a minimum of 65 feet in the upper Camp Nelson. The Eggleston thins from 150 feet at Hagan, Virginia, to 75 feet in the Tyrone of Kentucky. The interval between the corresponding metabentonites (*V4* and *V7*) thins from 40 feet at Harrogate, Tennessee, to 20 feet in Kentucky. The Curdsville thins from 40 feet to 20 and the Hermitage-Logana from 70 to 35.

The convergence of the *Cryptophragmus* beds, the Eggleston-Tyrone, Curdsville, and Hermitage-Logana from Lee County to central Kentucky is similar. The interval between the *Cryptophragmus* beds and the Eggleston-Tyrone decreases much more rapidly, suggesting the presence of an unconformity within the interval represented by the Oregon. The underlying *Cryptophragmus* beds as now known, converge about 35 per cent;

the Eggleston-Tyrone convergence is about 50 per cent. An anticipated convergence for the Oregon should be about 40 per cent. Assuming that no break exists at the base of the Moccasin in Virginia and granting that the Moccasin and Oregon are stratigraphically equivalent, the 300 feet of Moccasin should thin northward to about 180 feet. The Oregon has a maximum thickness of 35 feet, representing a thinning of about 90 per cent. This abrupt change in convergence suggests a hiatus at the base of the Oregon. If a hiatus exists at the base of the Moccasin in Virginia, then the break in the Kentucky section is considerably greater than indicated by the convergence (see Fig. 8).

More accurate dating of the St. Peter sandstone is made possible through convergence studies. Freeman[42] has recognized St. Peter sand in deep wells of Kentucky between the Knox dolomite (Beekmantown) and the Camp Nelson limestone. Isopachal studies by the same author, on the interval between the Pencil Cave clay (*V4*) and the top of the Knox dolomite, show northwest thinning across southern and central Kentucky. This thinning is supported by present convergence studies. The St. Peter is definitely younger than the Knox and older than the Camp Nelson. If the *Cryptophragmus* beds in the upper Camp Nelson are Pamelia in age, then the lower Camp Nelson is pre-Pamelia or Chazyan. The St. Peter sandstone lies above Beekmantown beds and below pre-Pamelia (Chazyan), indicating middle or lower Chazyan age.

Northwestward thinning of middle Ordovician units from southwestern Virginia to the Jessamine dome does not imply the existence of a Cincinnati axis during this time, inasmuch as certain Trenton structures were transverse to that line of reference.[43]

CLASSIFICATION OF VIRGINIA AND KENTUCKY SECTIONS

Correlation of the Virginia and Kentucky sections with the standard section of New York can be accomplished through Pennsylvania. According to Marshall Kay,[44] the Loysburg of central Pennsylvania, classed as Chazyan, is similar to the "Mosheim" and "Murfreesboro" of West Virginia and Virginia. The Hatter has the stratigraphic position of the "Lenoir" and "Ottosee," the upper Hatter (Hostler member) containing forms common to the upper "Rye Cove Ottosee" and the Benbolt of Tazewell County. The *Cryptophragmus*-bearing Benner, classed as Pamelia, forms the lowest "Moccasin" in Virginia, younger Black River (Curtin) being absent. The lower Trenton Nealmont lies with great regional unconformity and local marked disconformity on older beds. The Nealmont passes southward into red shale-bearing Moccasin and overlying Eggleston; metabentonites in the upper part of the basal Oak Hall member of the Nealmont have been correlated with those in the Eggleston. The middle Trenton Salona formation has *Cryptolithus tesselatus* and a zone of *Sinuites cancellatus* near the base. The lower Salona is correlated with the Shoreham of New York, the upper Salona with the Denmark. The Coburn limestone and the Antes black shale of the upper Trenton seem equivalent to

[42] Pp. 1836–43 of ftn. 2 (1939).

[43] McFarlan, "Stratigraphic Relationships of the Lexington, Perryville, and Cynthiana (Trenton) Rocks in Central Kentucky," *Bull. Geol. Soc. Amer.*, Vol. XLIX (1938), pp. 989–96; "Cincinnati Arch and Features of Its Development," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIII (1939), pp. 1847–52.

[44] "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. LII (1944), pp. 1–23, 97–116.

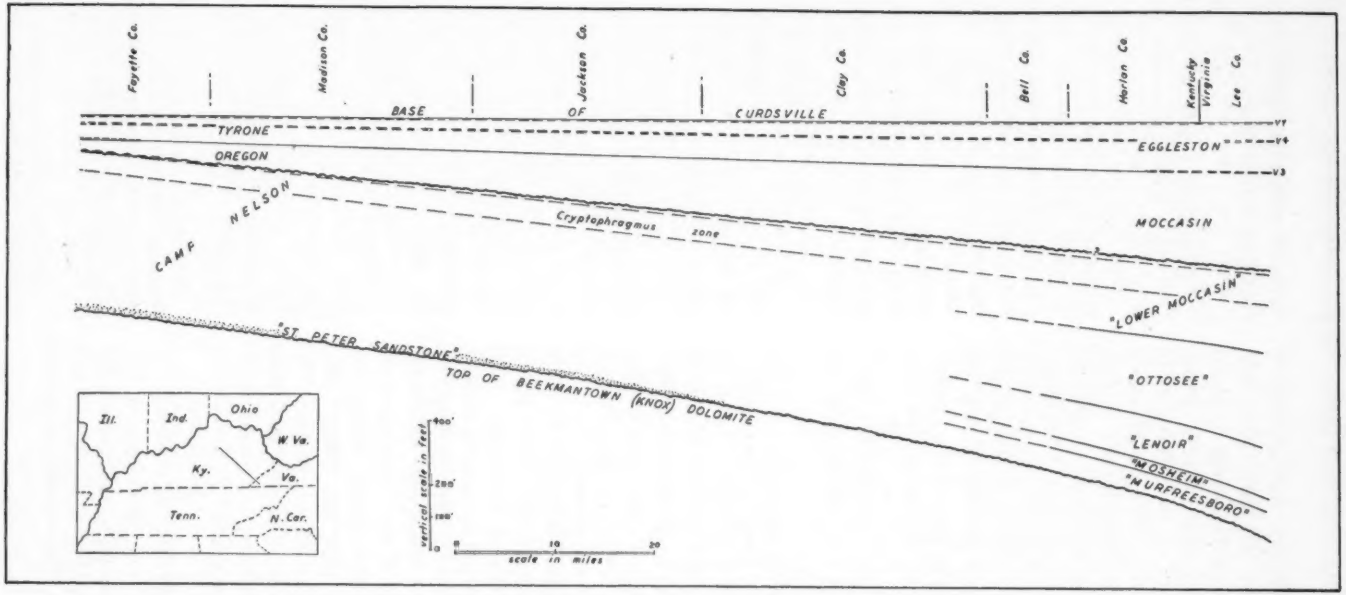

FIG. 8.—Diagram illustrating convergence of middle Ordovician units from Lee County, Virginia, to central Kentucky (data partly from Freeman)

the Cobourg and Holland Patent (Upper Utica) beds in New York.

Kay[45] correlated the Benner limestone, containing the *Cryptophragmus* beds in Pennsylvania, with the Pamelia, and the succeeding Curtin with the Lowville. ent in the Chaumont of New York, the Curtin must be older than the Chaumont. An alternative correlation has since been suggested.[46] Metabentonite *F* is the thickest in the Black River of Pennsylvania and that in the lower Low-

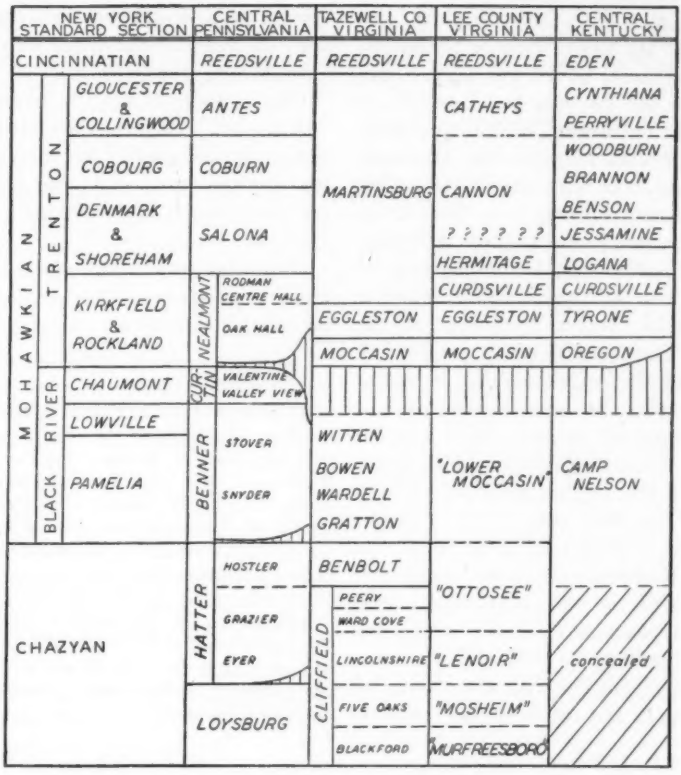

FIG. 9.—Middle Ordovician correlation table

Cryptophragmus ranges from the Pamelia into the Lowville in New York and Ontario. It was thought that metabentonite *A* in the top of the lower Curtin (Valley View) might correspond to that in the lower Lowville of New York and that, inasmuch as metabentonites are absent in the upper Curtin (Valentine) but pres- ville thickest in New York. If these are correlated, the *Cryptophragmus* zone remains in the corresponding units, the Benner being equivalent to the Pamelia and the Lowville. The Curtin (Valley View) contains several metabentonites, as does the lower Chaumont (Leray). Thus the correlation of the Benner lime-

[45] *Ibid.*, pp. 22–23.

[46] Kay, personal communication (May, 1944).

stone with the Pamelia and the Lowville, and the Curtin with the Chaumont, seems better than the earlier suggestion.

The *Cryptophragmus* beds of the upper Camp Nelson of Kentucky, the "Lower Moccasin" of Rye Cove and Lee County, Virginia, and the Witten limestone of Tazewell County, Virginia, correspond to the upper Benner formation of Pennsylvania, which has been correlated with the Pamelia and Lowville of New York. The lower Trenton Nealmont of Pennsylvania becomes the Moccasin and Eggleston of Virginia and probably includes strata equivalent to the Curdsville of Kentucky near the top. A regional unconformity may be at the base of the Moccasin of Virginia and the Oregon of Kentucky, strata equivalent to the Curtin (Chaumont) being absent. A metabentonite corresponding to metabentonite *F* of the upper Benner has not been recognized in the upper *Cryptophragmus* beds of Virginia. Lower Trenton age of the Eggleston and Tyrone is indicated by their conformity with the Curdsville, which has been correlated with the Kirkfield (Hull) of Ontario and New York on the basis of its echinoderm fauna. *Cryptolithus tesselatus* in the Logana ("Hermitage") of Kentucky correlates that formation with the Salona of Pennsylvania and the Shoreham of New York. The *Sinuites* zone in the lower Hermitage of Lee County may correspond to one near the base of the Salona; the latter formation carries a thick metabentonite near its base, clay *2* and a higher clay *3* which may correspond to the clay at 45 feet in the Hermitage. The Curdsville of southwestern Virginia has been included in the lower Martinsburg formation northeastward.

Chazyan age of the "Murfreesboro"–"Mosheim"–"Lenoir"–"Ottosee" sequence is indicated by its position above the Beekmantown dolomite and below the lower Black River (Pamelia) *Cryptophragmus* beds.

Tentative correlations of middle Ordovician sections mentioned in the text are included in Figure 9.

ACKNOWLEDGMENTS.—The field work which served as a basis for this report was done during the summer of 1942. Faunal collections were made and identified by the writer. The problem was suggested by Professor Kay, of Columbia University, who supervised and aided in the study. The writer profited by discussions with Dr. B. N. Cooper, of the Virginia Survey, and Dr. H. N. Coryell, of Columbia University. The manuscript was read and helpful criticisms offered by Dr. W. H. Bucher and Dr. C. H. Behre, Jr. Members of the faculty of Lincoln Memorial University, Harrogate, Tennessee, and of the Department of Geology of the University of Kentucky expressed a friendly interest in the work.

OBSERVATIONS ON PSEUDO-DIKES AND FOLIATED DIKES

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ABSTRACT

Criteria for distinguishing between dikes and pseudo-dikes (or xenoliths), particularly when both are foliated, are discussed in this paper. Consideration is given to time and direction of application of stresses which produced the foliation. Examples are mainly from southern California.

INTRODUCTION

When working in regions of crystalline rocks, special care must often be exercised in distinguishing between true dikes and pseudo-dikes (or xenoliths), particularly when both exhibit secondary structure. Thus, certain foliated dikes may easily be mistaken for xenoliths, and various xenoliths closely resemble dikes. Unusually deceiving are certain long, straight, narrow xenoliths, which upon casual examination would be called "dikes." Criteria for making the distinctions are discussed.

Most of the foliated dikes are in or near fault zones in which shearing stresses produce the foliation long after emplacement of the dikes. Some dikes show a primary structure, and still others show no foliation.

Foliation of pseudo-dikes may or may not have resulted from stresses developed during faulting.

KINDS AND AGES OF THE DIKES

The dikes and pseudo-dikes referred to in this paper are of various kinds and ages, most of them being well represented in the San Gabriel Mountains, the crystalline rocks of which are listed in Table 1. The rocks of particular interest in our discussion are Rubio diorite and metadiorite, dioritic facies of anorthorsite, fine-grained dioritic dikes, quartz-latite porphyry dikes, lamprophyre dikes, and basaltic dikes. Rocks like most of these occur also in various other parts of southern California.

TABLE 1

CRYSTALLINE ROCKS OF THE SAN GABRIEL MOUNTAINS

Tertiary	Volcanics Basaltic (or diabase) dikes Lamprophyre (or dioritic) dikes Quartz-latite porphyry (or porphyrite) dikes
Late Jurassic	Aplite, pegmatite, and silexite dikes Lowe granodiorite Wilson diorite
	Metasediments; probably late Paleozoic; eastern part only
	Fine-grained dioritic dikes; probably pre-Cambrian
Pre-Cambrian	Pelona schist; metasedimentary; probably late pre-Cambrian Anorthosite; bluish-gray, white, and dioritic facies San Gabriel formation; a complex of Placerita metasediments, Rubio diorite, and Echo granite Echo granite Rubio diorite; hornblende-rich; varies to metadiorite Placerita metasediments; probably early pre-Cambrian

PSEUDO-DIKES

In the course of field work in southern California many examples of pseudo-dikes have been observed by the writer. Eight of these will be discussed to show

the nature of the rocks and the phenomena involved. Two examples from other regions are also discussed.

FIG. 1.—Pseudo-dikes of biotite- and hornblende-rich metadiorite cut to pieces by granodiorite. Upper end of Little Rock Reservoir, San Gabriel Mountains, California.

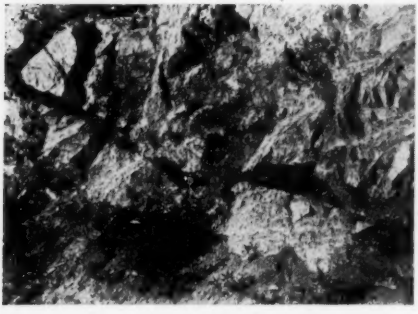

FIG. 2.—A pseudo-dike of metadiorite (largely biotite schist) with sharp contacts in pegmatitic granite. India Canyon Forest Service road, three-fifths of a mile from summit in western San Gabriel Mountains, California.

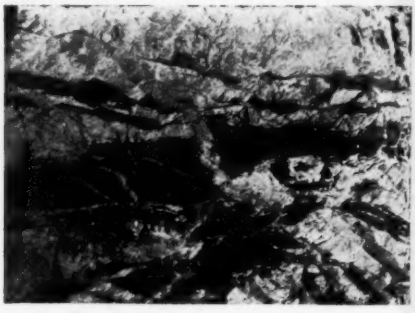

FIG. 3.—Part of the same outcrop shown by Fig. 2, with the metadiorite definitely in the form of xenoliths cut by dikes of the pegmatitic granite.

A very striking illustration of pseudo-dikes occurs near the upper end of Little Rock Reservoir in the northern San Gabriel Mountains. On casual examination this occurrence (Fig. 1) would easily be mistaken for a network of basic dikes in the Lowe granodiorite. They are, in reality, pseudo-dikes representing remnants of Rubio diorite cut to pieces by the granodiorite. Many granodiorite dikes—often tiny ones—plainly cut the dark, dikelike strips irregularly. The strips vary from massive to highly foliated and sheared. Many large and small xenoliths of the diorite occur in the general vicinity of the reservoir. Near the

dam, several small basic dikes of Tertiary age cut the granodiorite sharply.

By the India Canyon road in the northwestern San Gabriel Mountains, a sharply defined strip (xenolith) of metadiorite, varying to biotite schist (Fig. 2), lies in pegmatitic granite, the latter cutting near-by white anorthosite. Taken by itself, this xenolith would easily be mistaken for a much-sheared basic dike. Close by, in the same outcrop, however, strips of similar material are cut by various dikes of the pegmatitic granite (Fig. 3.)

A narrow, somewhat irregular strip of black metadiorite (Fig. 4), with sharp contacts, lies in light-gray massive granite on the Angeles Crest highway, about a mile below the Red Box summit. Its maximum width is 1½ feet. It is spotted with hornblendes, and it is probably a facies of the Rubio diorite. A tiny dike of the granite cutting across its eastern end proves that it is not a dike. Between this occurrence and Red Box there are a number of similar strips of metadiorite, some cut by granite dikes and others not.

Good examples of interesting pseudo-dikes are shown in a road cut about a mile east of Lang, near Soledad Sulphur Springs in the western San Gabriel Mountains. They are more or less sheared and foliated, earlier solidified, coarse-grained, dioritic facies of anorthosite in massive white anorthosite. One of these (Fig. 5), about 25 feet in length, is curved, varies greatly in thickness, and thins out at each end. Its xenolithic nature is proved by the fact that locally it is somewhat intimately injected by the anorthosite. Other dikelike xenoliths of

FIG. 4.—A dikelike xenolith of metadiorite with sharp contacts in gray granite cut by a tiny dike of the granite near the right end. Angeles Crest highway, 1 mile down from Red Box summit in western San Gabriel Mountains, California.

FIG. 5.—A sharply defined, variably sheared and foliated, dikelike xenolith of a dioritic facies of anorthosite in white anorthosite. Foliation is generally parallel to contacts. About 1 mile east of Lang in western San Gabriel Mountains, California.

FIG. 6.—A pseudo-dike of foliated metadiorite in coarse-grained, crudely foliated, bluish-gray anorthosite. Tiny sills of anorthosite cut the metadiorite. Angeles Crest highway southwest of the Monte Cristo Mine in western San Gabriel Mountains, California.

similar material in this vicinity are not cut by the anorthosite.

A dikelike strip or pseudo-dike of hornblende-rich metadiorite in coarse-grained, bluish-gray, crudely foliated anorthosite (Fig. 6) shows on the Angeles Crest highway southwest of the Monte Cristo mine in the San Gabriel Mountains. The anorthosite is somewhat contaminated by dioritic material. Foliation of anorthosite and pseudo-dike are parallel. A few tiny sills of anorthosite cutting the metadiorite prove that the latter is a xenolith.

FIG. 7.—Part of a remarkable dikelike xenolith of variably foliated, dark-gray metadiorite in light-gray quartz diorite. It disappears under the wash in the middle distance. About 5½ miles a little south of west of Coyote Well, Imperial County, California.

Northeast of Jacumba, in San Diego and Imperial counties, some of the many large and small inclusions of dark-gray metadiorite in light-gray quartz diorite may, from little distances, easily be mistaken for dikes. A good case in point is the pseudo-dike, 10–15 feet wide, extending across the face of a small mountain 3 miles northeast of Jacumba. Still finer examples occur 1–2 miles west of the mouth of In-Ko-Pah Gorge and about 5 miles west-southwest of Coyote Well. The one studied in detail is exposed for a distance of about 700 yards. It is 20–60 feet wide and remarkably straight (Fig. 7). The dark-gray, variably foliated, biotite- and hornblende-rich, fine to medium-grained pseudo-dike strikes nearly east-west across a low ridge of light-gray, massive quartz diorite and disappears under the desert wash on each side. Contacts against the diorite are generally very sharp. Dips of both pseudo-dike and its generally well-developed foliation are 50°–70° south. The following facts prove that we are here dealing with

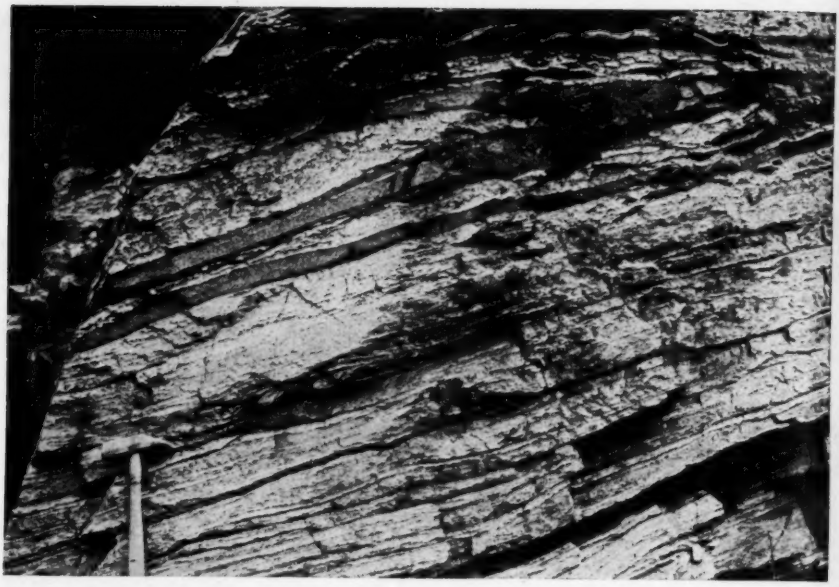

FIG. 8.—Sill-like xenoliths of metagabbro-diorite in foliated, gray, pre-Cambrian granite. Lower Gold Park Canyon, south of Twenty-nine Palms, California.

FIG. 9.—A basaltic dike in quartz monzonite. From a short distance it looks like a xenolith. A pseudo-dike of monzonite extends across it. About 20 miles south of Needles, California.

a xenolith: a few small dikes both of the diorite and of pegmatitic offshoots of it cut the pseudo-dike; and some strips of the metadiorite, about a foot in length, lie in the adjacent diorite, parallel to the pseudo-dike contact. Another similar pseudo-dike occurs about 600 yards farther south of the one just described and parallel to it. A lens of similar metadiorite, 60 feet long and 15 feet wide, lies in the diorite near by.

In lower Gold Park Canyon, south of Twenty-nine Palms, a number of pseudo-dikes of basic material occur as sill-like strips or bands in highly foliated pre-Cambrian granite. These strips have schistose borders about $\frac{1}{4}$ inch wide. The writer, in company with several graduate students, decided, after very careful study, that the dark strips in the highly foliated pre-Cambrian granite shown in Figure 8 are not sill-like intrusives in the granite but, rather, xenoliths of metagabbro-diorite in the granite. A study of near-by outcrops shows that these bands are metamorphosed remnants of a large body of gabbro-diorite border, portions of which were cut to pieces by the granite magma. Most of the remnants were largely injected more or less intimately, and even digested, by the granite. In this vicinity several small dikes of Tertiary basalt cut the granite-metagabbro-diorite complex sharply.

A small hill of massive, moderately coarse-grained monozonite, $4\frac{1}{2}$ miles south of Twenty-nine Palms, contains several nearly straight, narrow xenoliths of metadiorite which may easily be mistaken for dikes. These pseudo-dikes range in width to 1 foot and in length to 100 feet. The combination is cut sharply by a small, massive, fine-grained, basic Tertiary dike with chilled borders.

About 20 miles south of Needles numerous large and small dikes of basalt and quartz-latite porphyry cut quartz monzonite. One of the basic dikes (Fig. 9) could, from a little distance, easily be mistaken for a xenolith. It is 35 feet in length, and it ends abruptly at each end. It is fine grained and massive, with chilled borders. A pseudo-dike of the monzonite extends through it.

Two examples of pseudo-dikes outside of California will now be considered. One of these is by the highway 5 miles north of Schroon Lake in the Adirondack

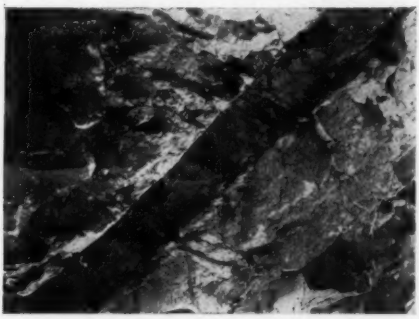

FIG. 10.—A dikelike xenolith of foliated garnetiferous, metagabbro, 18 inches wide, in light-gray, garnetiferous anorthosite. Five miles north of Schroon Lake, Adirondack Mountains, New York.

Mountains, where several sharply defined layers or bands of roughly foliated garnetiferous, amphibolitic material occur in poorly foliated, garnetiferous Whiteface anorthosite. Foliation of amphibolite and anorthosite are parallel. These layers are either highly altered metagabbro or mafic gneiss of Grenville origin. In either case, they are xenoliths; but they could easily be mistaken for dikes—one of them especially (Fig. 10). Close by, in the same outcrop, however, similar mafic bands are cut sharply by the anorthosite. Also, some small shreds of the mafic material have been variably digested by the anorthosite.

In 1938 the writer observed several in-

teresting pseudo-dikes, forming a parallel group in an outcrop near Molde, Norway. These are fine-grained, strongly foliated metadiorite, with sharp, somewhat irregular, boundaries, in foliated, pink, impure, pre-Cambrian granite. Foliation of pseudo-dike and granite are parallel. The smaller pseudo-dikes are seen to pinch out at each end. The largest one, exposed for 40 feet, is $1\frac{1}{2}$–2 feet in width (Fig. 11). A small pegmatite dike, derived from the granite magma, cuts this pseudo-dike very sharply; but the pegmatite is not sharply separated from the granite. Sharp contacts of the metadiorite against both the granite and the pegmatite and the highly foliated and sheared structure of the metadiorite rule out the possibility that we are here dealing with a true dike—even one which could have intruded the granite before final consolidation of the latter. F. F. Grout[1] has described a lamprophyre dike, believed to have cut syenite at Snowbank, Minnesota, before the syenite was entirely crystallized because some syenite cross-cuts the lamprophyre and also because a small pegmatite dike, derived from the syenitic magma, cuts both syenite and lamprophyre. In this case, however, the lamprophyre is massive and its contacts are not sharp.

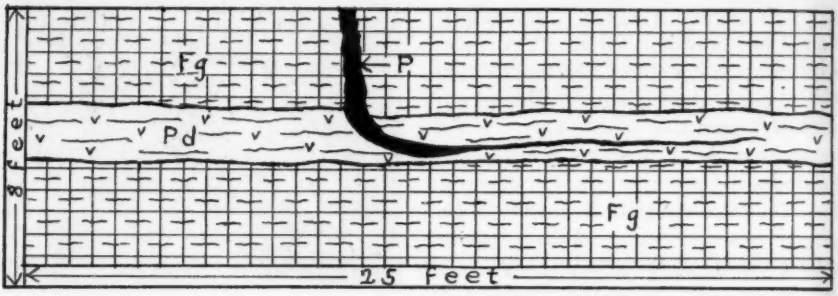

FIG. 11.—Ground-plan sketch of a strongly foliated, basic, pseudo-dike (*Pd*) with sharp contacts in moderately foliated granite (*Fg*). Both are cut by a pegmatite dike (*P*). Near Molde, Norway.

FOLIATED DIKES

In southern California, as elsewhere, many dikes exhibit varying degrees of primary foliation. In this paper, however, examples only of dikes which show secondary foliation are considered.

An interesting network of foliated basaltic dikes shows in a road cut about 1 mile west of Chilao on the Angeles Crest highway in the San Gabriel Mountains. They are of Tertiary age; they cut Lowe granodiorite sharply; and they run in all directions. Part of this network is illustrated by Figure 12, where the maximum dike width is shown to be $2\frac{1}{2}$ feet. Each dike is largely sheared into schist, with foliation always parallel to the walls, no matter how the dikes run.

Figure 13 shows a medium-fine grained dioritic dike 2 feet wide cutting horizontally across pre-Cambrian banded gneiss (on left) and pre-Cambrian diorite (on right) near Barley Flat in the San Gabriel Mountains. The borders of the dike, 2–4 inches wide, have been sheared into a hornblende-biotite schist with foliation paralleling the dike borders.

[1] *Petrography and Petrology* (New York: McGraw-Hill Book Co., 1932), p. 121.

FIG. 12.—Part of a network of schistose basaltic dikes in light-gray granodiorite. Maximum dike width is 2½ feet. Near Chilso in the western San Gabriel Mountains, California.

FIG. 13.—A medium-fine grained, probably pre-Cambrian, dioritic dike, 2 feet wide, cutting horizontally across pre-Cambrian banded gneiss (*on left*) and Rubio diorite (*on right*). Borders of the dike are schistose. Near Barley Flat in the San Gabriel Mountains, California.

Some small sheared masses also occur farther within the dike. This dike is probably pre-Cambrian.

On the Angeles Crest highway in lower Mill Creek Canyon in the middle-western San Gabriel Mountains a fine-grained dioritic dike, 1½ feet wide (probably pre-Cambrian), diagonally and sharply cuts strike and dip, and all are more or less foliated and sheared, always parallel to their borders. In Figure 15 two such dikes are shown sharply cutting white, nonfoliated, but much-fractured, white anorthosite. The small, dark, wedge-shaped mass lying between the two dikes is a xenolith of diorite representing an

FIG. 14.—A fine-grained dioritic dike, 1½ feet in width, cutting anorthosite with dioritic facies (*on left*). Wilson dioritic (*on right*) cuts both the anorthosite and the dike. Borders of the dike are variably sheared and schistose. Lower Mill Creek Canyon in the middle-western San Gabriel Mountains, California.

massive anorthosite which varies from nearly pure, bluish-gray to a dioritic facies, as shown in Figure 14. Narrow borders of the dike grade rapidly into schist as a result of shearing. Massive Wilson diorite, on the right in Figure 14, cuts both the dike and the anorthosite sharply.

Along the road in lower Soledad Canyon in the vicinity of Soledad Sulphur Springs, many foliated, basic dikes are excellently exhibited. They vary greatly in earlier crystallized facies of the anorthosite. The steep-dipping, nearly black dike is a medium-fine grained, hornblende- and biotite-rich metadiorite, which is probably pre-Tertiary. Its main, interior portion is only crudely foliated, but its borders are highly schistose and sheared parallel to contacts. It has been offset 3 feet by faulting. A younger, low-dipping, gray, fine-grained, basaltic dike follows the fault and crosscuts the black dike. It is highly sheared, usually schis-

tose, with foliation paralleling contacts. There are some remnants of chilled borders.

Near the outcrop just described, there are two other black, hornblende- and biotite-rich dikes of metadiorite (Fig. 16), similar to the one shown in Figure 15; but they dip steeply in the opposite direction. They vary from 18 to 36 inches in width. Some remnants of chilled borders are preserved in contact re-entrants. One of the dikes exhibits the usual border schistosity parallel to contacts; but its interior is diagonally well foliated and somewhat sheared, thus plainly indicating torsional stress or drag effect. The other dike is variably schistose throughout; but, where thickest, its interior is notably crumpled. Such phenomena have been observed much less conspicuously in a few other basic dikes in the San Gabriel Mountains. This is surprising, in view of the fact that so much secondary schistosity and shearing have been produced in the basic dikes.

One-third of a mile east of Soledad Sulphur Springs, and just east of the road tunnel in the western San Gabriel Mountains, there is a grand display of roughly parallel, basic dikes cutting white anorthosite. Figure 17 illustrates part of this dike system. These dikes are largely nearly black, fine to finer medium-grained, hornblende- and biotite-rich diorite of pre-Jurassic granite age. Dikes and sills of the granite, ranging from tiny to several feet in width, cut the basic dikes sharply. A few small, fine-grained, basaltic dikes of Tertiary age cut the dioritic dikes. Both dioritic and basaltic

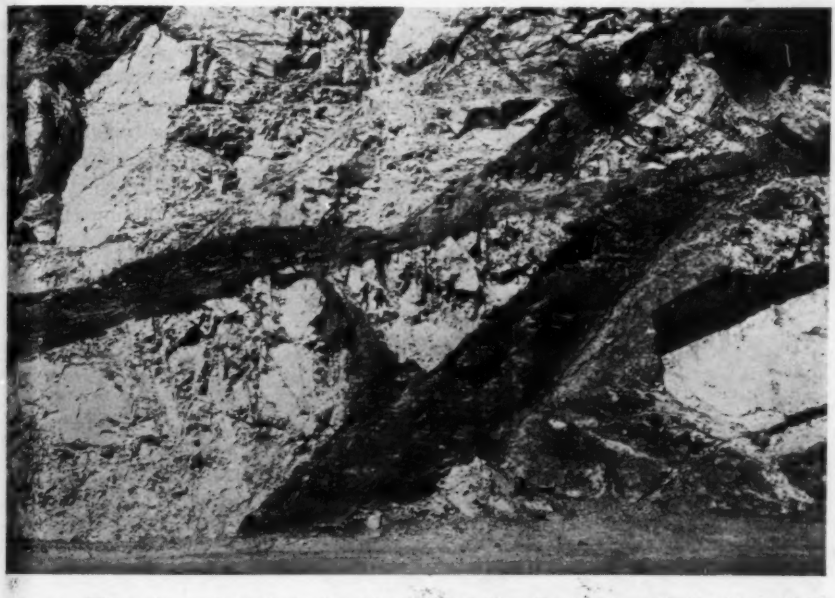

FIG. 15.—White, shattered anorthosite is cut by two basic dikes. One is a steep-dipping, black, biotite- and hornblende-rich dioritic dike with schistose borders and offset 3 feet by faulting. The other is a schistose basaltic dike of Tertiary age which follows the fault. East of Lang, near Soledad Sulphur Springs in the western San Gabriel Mountains, California.

dikes vary from massive to highly foliated; and both are locally crumpled, especially their border portions, but some remnants of chilled margins remain. A few small xenoliths or segregation masses of the earlier consolidated, now variably foliated, coarse-grained facies of the anorthosite occur here and there. Four of the rocks just mentioned are shown in detail in Figure 18. This occurrence is a little to the left of the general view illustrated by Figure 17. The white rock is anorthosite. At the lower left is a wedge of the black, foliated, dioritic facies of the anorthosite. All large and small, dark-gray dikes, sharply cutting the anorthosite in the upper one-half of the exposure, are variably foliated diorite. The gray, wedge-shaped mass with the hat on it is late-Jurassic, massive pink granite, sharply cutting the other three docks.

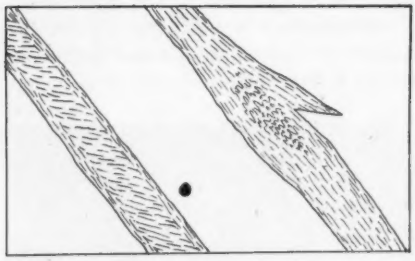

FIG. 16.—Black, fine-grained, schistose, dioritic dikes in medium-grained white anorthosite. One of these, 18 inches in width, shows diagonal, as well as marginal, schistosity; the other is foliated throughout, with crumpling in its thickest portion. Close to the dikes shown in Fig. 15.

Along the road for one-third of a mile

FIG. 17.—Part of a roughly parallel system of black, fine-grained, dioritic dikes cutting white anorthosite. A few small dikes of granite cut both anorthosite and diorite, and a few small basaltic dikes of Tertiary age cut the other three rocks. Both dioritic and basaltic dikes vary in structure from massive to schistose, but neither anorthosite nor granite is foliated. One-third of a mile east of Soledad Sulphur Springs, in the western San Gabriel Mountains, California.

east of the above-mentioned road tunnel in lower Soledad Canyon the main country rock is white anorthosite, cut irregularly and sharply by a good many of the dark-gray, fine-grained, biotitic diorite dikes. The larger ones have schistose borders. The anorthosite is cut very irregularly by much pink granite and pegmatite, small sills and dikes of which cut the basic dikes.

FIG. 18.—White anorthosite with a black, wedge-shaped xenolith of an earlier foliated, dioritic facies (*lower left*), cut irregularly by a system of black dioritic dikes with variable foliation parallel to contacts. A wedge of massive pink granite (*hat on it*) cuts the other three rocks. Just west of the more general view shown in Fig. 17.

An interesting case of two strongly foliated basic dikes in marble in the southern Sierra Nevada has been described by Cordell Durrell.[3] The foliation of each dike is parallel to the dike walls, while that of the country rock is nearly parallel to the plane of the picture (Fig. 19). Thus there are three directions of foliation mutually at right angles to each other. Durrell says that these dikes were intruded before metamorphism of the marble.

In various parts of southern California the writer has found quartz-latite porphyry dikes of Middle Tertiary age. They occur singly and in groups. They vary in width from a few feet to 50 feet. Contacts are sharp, and dips are steep. All have fine-grained groundmass, and nearly all are very massive. Exceptionally, some of these dikes are well foliated. This is true of a group of roughly parallel quartz-latite porphyry dikes in the Chocolate Mountains about 10 miles northeast of Niland. They cut quartz

[3] "Metamorphism in the Southern Sierra Nevada Northeast of Visalia, California," *Univ. Calif. Pub., Dept. Geol. Sci.*, Vol. XXV (1940), p. 113, Fig. 28.

monzonite sharply. One of these is shown by Figure 20. They are strongly sheared and are foliated parallel to their walls, with a dip of about 40°. A similar dike, strongly sheared and foliated, occurs near the mouth of Monumental Canyon southwest of Needles, and another 4½ miles east of Sidewinder Well in the Victorville region. The foliation is usually accentuated by crude bands of biotite or chlorite.

FIG. 19.—Two strongly foliated, basic dikes nearly at right angles to schistosity parallel to dike walls. Country rock is marble. Near Lemon Cove in the Southern Sierra Nevada, California. Photo by C. Durrell.

SIGNIFICANCE OF THE FOLIATION

By way of explanation of the secondary foliation in the above-described dike and of similar foliation in some of the pseudo-dikes, several factors should b

considered. It is probable that, in some measure, secondary foliation has been impressed upon, and accentuated by, primary foliation. In view of the fact, however, that many dikes of similar composition, but without primary foliation, occur in the same general regions above mentioned, such primary foliation may be ruled out as an important contributing factor.

Composition is an important factor. By far, most of the strongly foliated dikes above described are dioritic or even more basic, and they are rich in biotite and hornblende—minerals which favor development of foliation, even schistosity, under shearing-stress conditions. Few, if any, of the quartz-latite porphyry dikes and the still more numerous aplite dikes in the San Gabriel Mountains exhibit any secondary foliation. In many cases, however, they are much shattered. The few observed cases of strongly foliated quartz-latite porphyry dikes in other parts of southern California involve rocks containing several per cent of biotite or hornblende in a very fine-grained groundmass.

Most important in producing the secondary foliation of the dikes has been dynamic metamorphism under relatively shallow-zone conditions within the earth. The finest and most numerous examples of such foliated dikes observed by the writer in southern California occur in the San Gabriel Mountains. This whole mountain block of 1,200 square miles of crystalline rocks has been squeezed up thousands of feet between steep indipping faults during Quaternary time. During this time the whole block has shifted northwestward at least several miles. Thus there developed a strong torsional stress within the mountain block, resulting in a great number of large and small faults running in various directions. The writer has never seen another rock mass of comparable size so remarkably fractured and shattered, particularly along the more important fault zones. Conditions were exceptionally favorable for the development of shearing stresses. All, or nearly all, of the more strongly foliated dikes are in or near important fault zones, developed, and accompanied by more or less shearing, long after emplacement of the dikes—for example, Tertiary and older dikes foliated

FIG. 20.—Sheared and foliated quartz-latite porphyry dike in quartz monzonite. Foliation is parallel to walls of dike. Ten miles northeast of Niland in the Chocolate Mountains of southern California.

by Quaternary stresses. It is remarkable how effective components of stress have often been so distributed as to produce shearing and foliation in the basic dikes with widely variable trends even in single outcrops, as so strikingly exhibited in lower Soledad Canyon. Evidently, these basic, biotite- and hornblende-rich dikes in or near fault zones were very susceptible to shearing parallel to their walls, no matter what their strike and dip. In this connection, it is important to note that the adjacent country rocks—usually medium to moderately coarse-grained anorthosite or quartz monzonite—were much shattered but not foliated. All this indicates that the dike foliation developed under relatively shallow condi-

tions and that the amount of movement during the shearing of any dike was not more than a few inches.

The writer has observed many basic dikes, particularly those of Tertiary age, which are not foliated in the San Gabriel Mountains. These are largely in localities well away from prominent Quaternary fault zones, but some (e.g., West Fork San Gabriel Canyon) occur in older fault zones in which little or no movement has occurred since the dikes were emplaced.

In the case of the above-mentioned quartz-latite porphyry dikes—much poorer in minerals favorable to development of foliation—only those striking parallel to near-by important fault zones became secondarily foliated. In these dikes foliation paralleling the faults was produced. This is conspicuously true of the group of such dikes close to the San Andreas fault zone 10 miles northeast of Niland, where the dikes are strongly sheared and foliated and the country rock of quartz monzonite is badly shattered.

The already mentioned foliated, basic dikes occurring near Lemon Cove in the Sierra Nevada do not seem to be associated with a fault. They are regarded by Durrell as premetamorphic dikes whose secondary foliation in different directions was produced by components of stress at the time of folding and metamorphism of the country rock, which is marble. Probably in this case the relatively weak marble yielded to stress by folding and flowage, while the more resistant basic dike material yielded to components of the stress by shearing.

Some of the xenolithic pseudo-dikes, under favorable conditions of mineral composition and position with respect to fault stresses, were secondarily foliated in a manner similar to that of the foliated dikes. A good example is shown by Figure 5. In most of these cases, however, foliation is believed to have developed before or during the time of intrusion of the enclosing country rocks, with possibly some later accentuation of foliation.

According to P. Eskola,[3] narrow dikes of amphibolite with "parallel metamorphic structure" and with no definite strike occur in various parts of southern Finland. He describes several, stating that they are dioritic and basaltic in composition. And he says that "to explain the origin of the foliation it is not necessary to assume orogenic movement and stress in more than one direction"; that hornblende could result from the metamorphism; and that, in "accordance with the principle of Riecke, the individuals of this mineral, when crystallizing under stress, would assume a parallel arrangement" in the direction of the strike of the dikes. With this explanation the writer is in partial agreement; but, in the cases described in the present paper, a considerable component of stress has also often produced notable shearing in the dikes parallel to their walls. Also, instead of a general regional pressure, stresses, developed in or near important fault zones, caused the foliation of the southern California dikes. This may explain why groups of dikes, as well as individual dikes in southern California exhibit such striking local variations in degree of foliation, as compared to the greater uniformity in those of Finland. Eskola believes that recrystallization of original dike material was very important; but the present writer believes that foliation of the southern California dikes has resulted from dynamic metamorphism, involving little, if any, recrystallization.

[3] "Petrology of the Orijärvi Region in Southwestern Finland," *Bull. Comm. Geol. de Finland* No. 40 (1914), pp. 113–18.

THE PHYSIOGRAPHIC HISTORY OF AN EOCENE SKYLINE MORAINE IN WESTERN MONTANA

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ABSTRACT

Gravelly Range in southwestern Montana has long attracted attention because of the huge amount of loose, water-worn material along its crest. Our studies in that range have demonstrated that the material along the skyline, in large part at least, is a glacial moraine. Some of the finer material may be outwash associated with glaciers. This moraine was deposited by alpine glaciers which descended from mountains that no longer exist and was placed in a valley during Eocene time. There it remained through the long periods of mid-Tertiary erosion when the widespread Rocky Mountain peneplain was developed. Today, owing to the subsequent uplift and erosion of the range, it is the high place or crest of a mountain range.

INTRODUCTION

On the crest of a subdued mountain area, between the Madison and Jefferson valleys and extending southward from Virginia City, there is a huge amount of bouldery and gravelly material which has attracted the attention and interest of many prospectors and students of geology. The highland mass upon which this loose or uncemented material rests is known as the Gravelly Range. To the northward are the Tobacco Root Mountains. To the west and about parallel to the Gravelly Range are the Green Horn and Snowy Crest Mountains. Eastward, across a broad valley lowland, are the rugged peaks of the Madison Range (see Fig. 1).

There are those who believe that the rich placer deposits of Alder Gulch, west of Virginia City, must have come down the slopes of the Gravelly Range. Many have prospected over and over again in the crest-line accumulation of gravelly materials. There they have found gold. Perhaps there is a relationship between these two deposits, but that can best be suggested after we have presented an analysis of the problems involved in a study of the physical history of this skyline moraine. The story to be told reflects the history of the entire mountain area during the last fifty to sixty million years.

In the summer of 1941, while we were on a brief reconnaissance visit in this part of Montana, the high-level bouldery deposits near the southern end of Gravelly Range impressed both of us as of some very special significance, and we naturally formulated working hypotheses that needed to be tested. In July, 1944, the senior author revisited the area.

THE MORAINIC MATERIAL

The largest of the boulders in this deposit, 10–12 feet in diameter, are granites, gneisses, or schists. Associated with the coarsely crystalline rocks are immense quantities of quartzites and fine-grained, dark-colored igneous rocks with pebbles and cobblestones of quartz, jasper, porphyry, and conglomerate. A few boulders were found that are presumably from a pre-Cambrian conglomerate, containing quartz pebbles and many pieces of jasper that are well worn. This conglomerate is a very hard, compact, and ancient-looking rock, like many of the pre-Cambrian conglomerates of the western mountain areas. On some of the fine-grained, black igneous pebbles of the gravelly deposit, glacial striae are still

preserved. This aggregation of crystalline and metamorphic materials suggests a pre-Cambrian complex as a source.

The skyline moraine rests upon Cretaceous sandstone and shale. The underlying formations dip gently to the westward, and the harder strata have caused the development of a series of cuestas with east-facing escarpments in which the different strata in the sedimentary rocks are well exposed.

The best and most striking examples of striation and grooving are on certain of the huge gneisses and granite masses. The one shown in Figure 2 is a gneissic boulder, with the color bands running transversely to the lines of grooves and scratches. The surface of this boulder is now somewhat pitted, for it may have been exposed for many years to the processes of weathering. Numerous other boulders showed evidence of intense glacial rubbing, polishing, planation, and striation.

Much of this bouldery mass is wonderfully well exposed in west-facing escarpments along the crest of the range south of Black Butte. At this place the escarpment is due to the preserving effect of the morainic capping. In the moraine there is a large amount of material so beautifully water worn that it gives the impression, when first examined, that it must be a stream deposit. By far the greater part of this moraine is water worn, but in the mass there are many subangular rocks that show very little water wear. The deposit shows no sign of stratification or even the rough assortment of materials commonly present in stream-deposited sediments. In Figure 3 it is clear that the material is not assorted.

The large masses of morainic materi

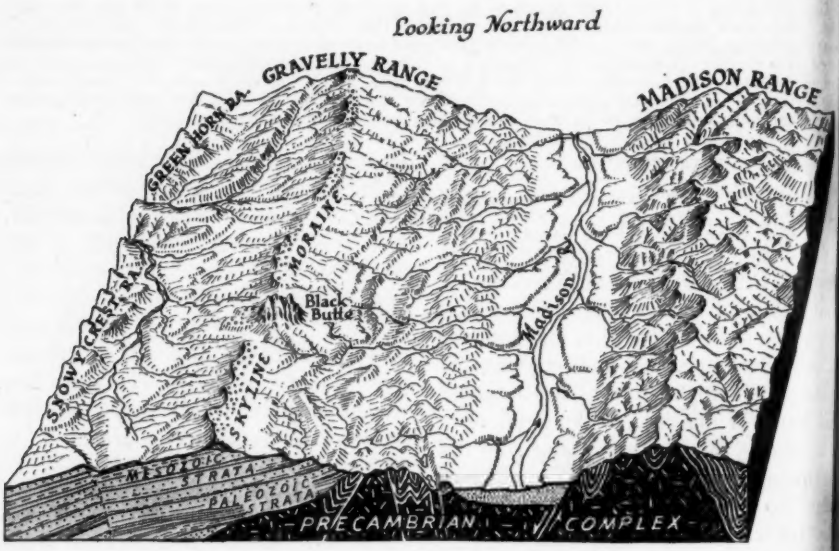

FIG. 1.—A simplified structural section and relief sketch. There is no accurate map available on a scale which would carry as much detail as is shown here.

FIG. 2.—A glaciated gneissic boulder about 10 feet long, located near the crest of Gravelly Range. The gneissic texture is at right angles to the glacial striae and grooves.

FIG. 3.—An exposure in the skyline moraine on the crest of Gravelly Range about three miles south of Black Butte.

now present are presumably but remnants of a much more extensive glacial deposit. The moraine is 50–100 feet thick at several localities at or near the crest of the range. One of the best exposures extends for about 2 miles along the crest of the range south of Black Butte. Other large remnants are north of Black Butte.

SOURCE OF THE SKYLINE MORAINE

In 1941 we found evidence which indicated that this crest-line material must be of glacial origin; but we were puzzled as all students of this problem must have been puzzled, in finding what seemed to be a moraine along the divide of a mountain range. Where could the materials have come from? There are no cirques or U-shaped canyons through which it could have moved to this location. There is no higher place in the present topography from which this material could have come. Black Butte (10,546 feet), the only higher rock mass near the crest of the range, is composed of extrusive basalt, but it did not contribute to the materials in this moraine. Furthermore, it shows no signs of glaciation. We are certainly not dealing with a Pleistocene moraine.

Since most of the very large striated boulders in this skyline moraine are crystalline and metamorphic, they must have been moved by ice from outcrops 10–15 miles away, where such rocks occur. The conclusion is unavoidable that the entire mass must have moved downhill, and therefore we must imagine remarkable changes that have taken place in this region since the moraine was deposited. The crest line of Gravelly Range, where the moraine now rests, must have been, at some time in the past, the low place or valley bottom in an ancient topography. Where there is blue sky today, there were lofty mountains with perennial snow fields, which gave rise to alpine glaciers. The present crest of the range was the floor of a mountain canyon through which a great mass of debris-laden ice moved. That must have been in Eocene time when lofty mountains with alpine glaciers existed in various parts of the Cordilleran province of North America. A mountain landscape in which there were many glaciers has disappeared. An old valley floor has become the high-line divide of a mountain range of a later generation.

During field studies conducted in July, 1944, the locations of the Black Butte tillite were visited, the character and distribution of the crest-line moraine were rechecked, and the areas of pre-Cambrian rocks near the southeastern margin of Gravelly Range and in the neighboring mountain area farther to the east were visited. There is no suitable topographic map published for the Gravelly Range area, but the heaviest and most continuous masses of the crest-line moraine are located on sketch maps drawn in the field (see Fig. 1).

Gravelly Range is not a rugged mountain area. The mountain tops have been very much softened and subdued by erosion, and there is abundant evidence of an old-age topography in the summit area. Viewed from the Madison Valley to the east, the skyline of Gravelly suggests a peneplain surface. When seen from good outlook points in the range the peneplain can be easily reconstructed in imagination; but it is evident that this old-age erosion surface has been uplifted and dissected. The mountain forms of today are due chiefly to the dissection of a peneplain. Our studies throughout the Rocky Mountain region lead us to believe that many of the surfaces in this range are remnants of the widespread Rocky Mountain peneplain developed during mid-Tertiary time.

This area has been peneplained, uplifted, and dissected since the moraine was deposited; and its modern valleys contain quantities of boulders, presumably derived from the moraine. A considerable number of large granite boulders were found in the headwaters of Gazelle and Barnett creeks. Barnett contains the best examples of striated boulders. They can be seen today on their downward journey from the moraine on the divide between the east- and west-flowing streams of Gravelly Range.

OTHER EOCENE MORAINES

Harold W. Scott reports finding glacial material underneath the Black Butte basalts and concludes that the deposit is of Eocene age.[1] Mr. Scott reports that he has found well-striated glacial stones in the deposit near the southwest margin of Black Butte and, overlying the tillite, an andesitic tuff, which is, in turn, overlain by the Black Butte basalt. The glacial deposit, which he calls the "Black Butte till," rests upon Cretaceous sandstones and shales at that locality, and it is undoubtedly part of the system of moraines reported in this article. Because of the geologic sequence, Mr. Scott is perfectly justified in correlating the deposit which he discovered with the Ridgway tillite discovered by the senior author of this paper in 1915.[2] He correlates it also with a similar deposit discovered in British Columbia by C. W. Drysdale.[3] He also relates his discovery to Eocene deposits of glacial till in Colorado reported by the two authors of the present article.[4] Mr. Scott reports the deposit of till as varying in thickness "from a thin veneer to as much as 200 feet." He refers to Black Butte and the associated basalts and tuffs as of mid-Tertiary age.

THE PHYSIOGRAPHIC HISTORY

In reviewing the physiographic history of the skyline moraine on the Gravelly Range we must think back to the time when the first uplifted masses of the Rockies were being carved into bold, rugged features with large catchment basins in which snows accumulated. The Rocky Mountain ranges were all brought into existence in the great Laramide revolution at the opening of Tertiary time. As uplift proceeded, weathering and stream erosion began in each range; and, as time passed, bold majestic mountain forms may have characterized the topography of the Eocene landscape.

In those ancient mountains that no longer exist the Ridgway tillite and the other Eocene tills of about the same age were deposited. They have been discovered in various parts of the Cordilleran section of the continent and undoubtedly will be reported from many other localities in the western mountains of the United States and Canada. In or near the area of the Gravelly Range there were mountains composed of the pre-Cambrian complex of granites, gneisses, schists, quartzites, conglomerates, and fine-grained igneous rocks. Other mountains made of sandstones, limestones, and shales were located west of the pre-Cambrian rocks above the present Gravelly Range. They were carved out of the bedded formations that rested on the slopes of the ancient core-rocks (see Fig. 1).

In the mountains of Eocene time,

[1] "Eocene Glaciation in Southwestern Montana," *Jour. Geol.*, Vol. XLV (1938), pp. 628–36.

[2] "Eocene Glacial Deposits in Southwestern Colorado," *U.S. Geol. Soc. Prof. Paper 96B* (1915).

[3] "Geology of Franklin Mining Camp, British Columbia," *Geol. Surv. Canada, Mem. 56* (1915).

[4] "The Gunnison Tillite," *Jour. Geol.*, Vol. XXXIV (1926), pp. 612–22.

snows accumulated and formed alpine glaciers, which descended into the valleys of that ancient mountain area. The crest line of the Gravelly Range of today was, at that time, the low place—the place toward which the streams flowed, toward which the ice moved. It was the place where the debris of streams and of the ice of that day was deposited.

During the long mid-Tertiary period, throughout the Rocky Mountain region erosion was going on in a vigorous way, and in the great orographic lowlands between the mountain ranges vast quantities of material accumulated. That was a period of erosion and of filling. As presented by the present authors in 1938,[5] this was the time when a widespread cycle-end surface was developed. In most of the mountain ranges thus far examined, extensive areas were reduced to the peneplain stage. In many instances a chain of crest-line peaks rose above that peneplain as monadnocks. The Snowy Range in the Medicine Bow Mountains is a good example. Another excellent example is seen in the crest-line peaks of the Wind River Range. Pike's Peak, Long's Peak, and other crest-line peaks in the Front Ranges of Colorado are monadnocks, remnants of mountains that were formerly thousands of feet higher. Mount Uncompahgre, Mount Sneffels, and the Needle Mountains, in the San Juan area of southwestern Colorado, are other examples of monadnocks rising above that erosion surface which developed near the close of the mid-Tertiary period of degradation and aggradation.

The cycle-end surface was produced during the millions of years that elapsed from late Eocene time to about the opening of the Pliocene epoch. That was an era when stream erosion continued with but local interruptions in the mountain ranges of the Rocky Mountains. The erosion surfaces which developed in the different ranges at this time are the most widespread of all such surfaces in the Rocky Mountain region, and we prefer to group them together and refer to this composite erosion surface as the "Rocky Mountain peneplain."

It was during this same long period of mid-Tertiary erosion that a vast amount of valley-filling was taking place. Huge quantities of fine material accumulated in the intermountain lowlands and on the great plains east of the Rocky Mountains. In the basin region of Wyoming the alluvial waste actually buried the granite ranges of that area. It was then that the Bozeman beds accumulated in many of the valleys of western Montana. Those beds contain vast quantities of volcanic ash, and some are beds of lacustrine origin.

In many parts of the Rocky Mountain region vulcanism played a large part in the activities of mid-Tertiary time. The lava plateau of the San Juan Mountains was built up during this period. The Absaroka plateau of volcanic materials came into existence, and the vulcanism of Yellowstone National Park dates from this same period of time. In the Crazy Mountains and at many other places lavas were poured out on the surface of the country. In the Gravelly Range, Black Butte and associated flows of lava, which appear to have come through fissures, are of mid-Tertiary age.

The long cycle of erosion, during which the peneplain surfaces were developed and the valley lowlands largely filled with debris, was closed in about mid-Pliocene time by a general uplift of the whole Rocky Mountain region. The

[5] "A Working Hypothesis for the Physiographic History of the Rocky Mountain Region," *Bull. Geol. Soc. Amer.*, Vol. XLIX (1938), pp. 957–80.

mountain ranges, where movement had been started at the opening of Tertiary time, were somewhat more uplifted than the intermontane lowlands. This emphasized the mountains and soon gave increased relief to the general landscape. At many places faulting occurred at the margins of the ranges, and in some cases the movement is measured by thousands of feet. Faulting helped to define many of the ranges in western Montana. At the east margin of the Gravelly Range, near the south end, there is evidence of recent faulting. At the west base of the Madison Range there is abundant evidence of slipping.

In the immediate vicinity of the Gravelly Range the Madison and Jefferson valleys were filled, nearly if not quite, to the peneplain level with alluvium that came from the adjoining mountains as the erosion of the highlands proceeded. The situation in the Madison Valley is of special interest, for that valley still contains hundreds of feet of alluvial wash from the neighboring ranges. Some of it is deltaic in structure, which means that a lake existed in this valley for a time. It is a bouldery, gravelly deposit in the bench lands used by the ranchmen for crops or as pastures. At the north the broad lowland of Madison Valley comes suddenly to an end at the Norris Hills. There the present Madison River plunges into a gorge, which it follows for several miles. The river is an antecedent stream and one that was superimposed. Perhaps the mid-Tertiary alluvial filling of this area entirely covered the Norris Hills; perhaps it rose 1,000 feet on the sides of the Madison and Gravelly ranges that border the present Madison Valley depression. The river flowing at that higher level found its way northward to join the Jefferson and the Gallatin near the present location of Three Forks to make the Missouri River.

When the Madison River, flowing on a mid-Tertiary alluvial surface, was rejuvenated during the Pliocene uplift, it began at once to lower its channel through the alluvium into the hard rocks beneath. In time it became superimposed upon the hard rocks and began cutting the narrow V-shaped gorge east of Norris. It has cut a valley through the Norris Hills and excavated the modern valley of the Madison Valley, upstream from the Norris gorge. At the south end of the Norris gorge the stream has been ponded, and a reservoir is maintained for electric power. If the entire gorge was filled, much of the Madison Valley lowland soon would be flooded.

Similar stories are associated with many of the valleys of western Montana; for most of the streams have been superimposed upon mountain ridges which were buried during the period of mid-Tertiary filling.

By the close of the long cycle of erosion and deposition of mid-Tertiary time, the summit of Gravelly Range must have had very little relief. The main crest and many of the secondary cuesta forms in their summits appear to be parts of the Rocky Mountain peneplain. The modern valleys all date from the uplift of that surface and are clearly due to the dissection of the peneplain.

Black Butte now rises to an elevation of 10,546 feet and about 1,500 feet above its immediate surroundings, for the crest line of the range is at about 9,000 feet. It may well have been a much more conspicuous peak than it is today. The belt of pre-Cambrian rocks at the southeast margin of the range has given rise to an area of softened hills, in which the schistose character of much of the rock has produced an alignment of some of

the elevations. The granite and gneissic masses have produced other rounded hills or low mountains. The harder strata in the inclined sedimentaries that constitute the major portion of Gravelly Range have produced the cuestas that may have remained, even during the peneplain stage. They are conspicuous features in the central portion of the range today. Lava caps like that on Lion Mountain and Flatiron Mountain have preserved those elevations a little above the general level of the peneplain.

The skyline moraine, which is the center of interest in this article, may have stood for a time a little higher than some of the hills of sandstones and shales, for gravels and boulders associated with sands often serve as a preserving cap in the landscape. Rain waters sink into such deposits and therefore do not erode them so rapidly as they do a cemented rock formation. Boulder caps and gravel caps often have the effect of preserving the summit areas of monadnocks.

THIS MORAINE AND THE ALDER CREEK GRAVELS

The general uplift that came during Pliocene time rejuvenated all streams in the Rocky Mountain region and resulted in the dissection of the cycle-end surface developed during mid-Tertiary time. The development of all or nearly all the valleys in that part of the continent dates from that uplift. No positive evidence of Pleistocene glaciation was noted in the portion of the range which we have examined. There are many examples of landslides, solafluction, and névé work but no modern glacial cirques, no modern U-shaped glaciated valleys, and no recent moraines.

Perhaps this story of Gravelly Range throws a little light on the intricate history of Alder Gulch, where millions of dollars' worth of gold have been recovered. Alder Gulch is one of the valleys cut into the mountain area since the Pliocene uplift, that is, after the close of that long mid-Tertiary period of erosion and deposition and long after Eocene glaciation. As the range was dissected, whatever material there was available was washed into the modern valleys and the re-washing of gravels that were on the summit of the range might well have led to a greater concentration of the gold content of such gravels.

Since gold has been recovered in some of the gravels associated with the summit of the range and there are many claims staked out along that crest line, it is interesting to imagine the streams and glaciers of the Eocene period of erosion, working when mountains existed that are no longer present in the region, having done the first work of concentrating gold in the stream bottoms in this part of the West. The gold which accumulated in Alder Gulch may first have been brought to the summit areas of the mountains and in the later cycle of erosion been concentrated in the younger valleys.

The studies here reported were not undertaken with the purpose of throwing any light on the history of the gold-bearing gravels near Virginia City; but no one can visit that region and show any interest in the mountain area without being asked many times where those gold gravels came from. There are prospectors and others today who would mortgage their homes to discover the answer to that question. Perhaps these studies may lead to a further examination of the area with the idea of throwing more definite light on the stages in the history of the gold which has concentrated in Alder Gulch.

THIS MORAINE AND THE PHYSICAL HISTORY OF THE ROCKY MOUNTAINS

The interpretation herein presented of the skyline moraine on the Gravelly Range fits perfectly into the general hypothesis which we have reported for the physical history of the Rocky Mountains. No one should now be surprised at finding gently rolling erosion surfaces near or at the summit of a range. The chances are that they are parts of that widespread Rocky Mountain peneplain that has been described and defined over and over again. No one should be surprised to find almost anywhere in the Rocky Mountains remnants of the Eocene glacial moraines. They were undoubtedly widespread and may have been very abundant during that glacial age and for a long time after that period.

The unique situation which we are reporting here is a moraine that must be of Eocene age which is not covered by any mid-Tertiary or younger formations. It rests on the summit of a range. As far as we can determine, it never has been covered, but during the physiographic history of the area it has gone through a series of interesting changes in its topographic relationships. When deposited, it was in the low place of a mountain area. Those mountains were worn away, and it came to be a part of a widespread surface of erosion. Then that surface was uplifted and dissected, but as yet it has been left, and it serves as the high place and the drainage divide in the range of today. This moraine has rested where it now lies for 50 or 60 million years. Since the late Pliocene uplift it has come to be a crest-line moraine on a mountain range. It will not remain much longer.

STREAM SELECTIVITY IN THE MIDDLE APPALACHIAN VALLEY

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ABSTRACT

Cambro-Ordovician limestones and Ordovician shales largely underlie the Great Appalachian Valley between Virginia and Pennsylvania. By differential erosion the limestone areas have been lowered considerably below the level of the shales; but, in spite of this obvious weakness of the limestones, Conococheague Creek and other streams show remarkable adjustment to shale belts. These courses are interpreted as subsequent and as due to the greater weakness of the shales toward concentrated stream erosion, whereas the limestones have been dissolved by unconcentrated rainwash. No change in climate seems necessary to explain this stream selectivity.

Between Chambersburg, Pennsylvania, on the north and the Potomac River on the south the most important stream draining the Great Valley is Conococheague Creek. This part of the Great Valley, as is generally true for its entire length, is developed on Cambro-Ordovician limestones and Ordovician shales, whose lesser resistance to erosion, compared with the older rocks on the east underlying the Blue Ridge province and the younger conglomerates and quartzites making the Appalachian ridges, is responsible for the lower elevations of the Valley. Structurally, the Valley rocks are continuously but openly folded and in many places faulted,[1] with the structure determining the major topographic trends, here somewhat east of north.

Two major topographic levels characterize the Great Valley in the Chambersburg region; the higher of these, occurring at elevations of 700–750 feet on hills of Martinsburg shale west of Chambersburg, descends to elevations of 550 feet on hilltops of the same shale near the Potomac River. This surface is generally known as the Harrisburg peneplain; and it is, to a very remarkable degree, now preserved only in the Ordovician shale areas. In passing from the Martinsburg areas to those underlain by the Cambro-Ordovician limestones, one commonly drops down over a steep grade to a surface lying between 100 and 200 feet below the Harrisburg surface on the shale. This lower surface, restricted to the limestone, has been termed the "Somerville peneplain." It is best developed on the purer limestones, whereas impure and cherty limestones may rise above it toward the Harrisburg level. This two-story character of the Great Valley is well developed from New Jersey southward at least to Virginia.

The occurrence of these two levels is usually explained by the statement that, following the Schooley cycle of peneplanation, evidences of which remain on top of the Blue Ridge and the Appalachian ridges, rejuvenation caused the erosion of the Harrisburg peneplain across the limestone and shale areas of the Great Valley indiscriminately. Uplift then occurring in the resulting partial cycle, time was allowed for local peneplanation of only the weaker-rock areas, and hence the limestone alone was reduced to the Somerville level. This his-

[1] G. W. Stose, "Mercersburg-Chambersburg Folio," *Geol. Atlas of the United States, Fol. No. 170* (Washington, 1909).

tory demands that the Valley limestones be less resistant than the shale toward processes of denudation. Geologic maps of the Mercersburg and Chambersburg, Pennsylvania, quadrangles show, however, that to a very notable extent the larger streams are located upon the Martinsburg shale, presumably the more resistant rock. From Chambersburg to the Potomac, a distance of about 25 miles, the Conococheague Creek confines its rambling and entrenched meandering course largely to the shale; and the West Branch of the Conococheague, flowing eastward out of the Appalachian ridges, turns southward to follow a shale outcrop for 6 miles between limestones on each side before it cuts eastward across one limestone belt to join the Conococheague on another shale belt. Thus the problem is to explain why the Conococheague follows the shale in an area where the lower regional elevation of the limestones suggests that streams should be subsequent upon them.

Still more striking stream adjustment to the shale is seen along the very meandering lower course of Conococheague Creek between the Pennsylvania boundary and the Potomac River. This region is shown on the Williamsport, Maryland, quadrangle; and the course of the Conococheague has been figured[2] and briefly discussed in *Guidebook 7, 16th International Geological Congress.* As shown in Figure 1, Conococheague Creek, flow-

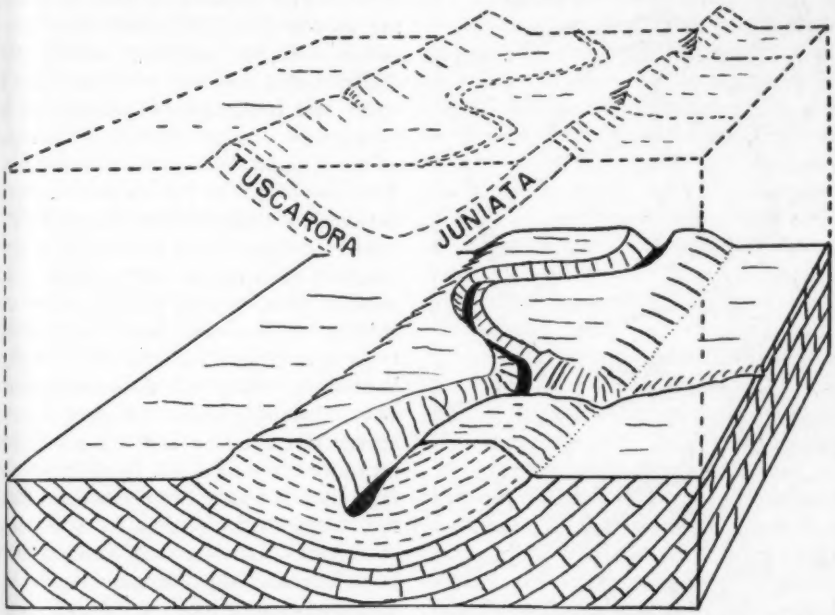

FIG. 1.—Diagram showing synclinal position of Conococheague Creek on shale belt. Top part of diagram shows supposed position of creek in Schooley time, according to hypothesis of inheritance set forth in *Guidebook 7.* (Modified from *Guidebook 7, 16th Internat. Geol. Cong.*).

[2] D. Johnson, F. Bascom, and H. S. Sharp, "Geomorphology of the Central Appalachians," *Guidebook 7, 16th Internat. Geol. Cong.* (Washington, 1932). See p. 45 and Fig. 26.

ing in an entrenched meandering course, is confined to a belt of shale with the older limestone on each side. The shale belt is about 2½ miles wide and occurs along

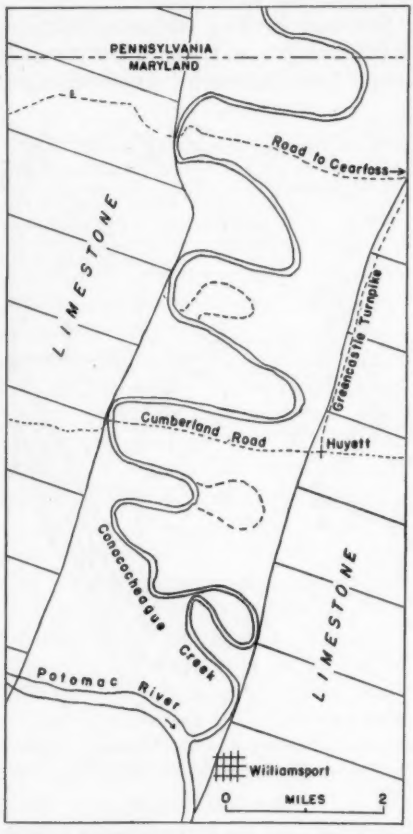

FIG. 2.—Map showing course of Conococheague Creek between Pennsylvania boundary and Potomac River with respect to limestone and shale areas. Heavy broken lines show abandoned high-level meanders.

the axis of the Massanutten syncline. Broad hilltop remnants on the shale at elevations around 560 feet apparently preserve the Harrisburg peneplain and form a broad, dissected, synclinal upland standing above the limestone areas to east and west. Considerable areas underlain by the limestone are less than 500 feet in elevation; and an observer on the limestone looking toward the shale upland from either direction, but particularly from the east, finds the contrast in elevation very conspicuous. From Cearfoss, Maryland, south nearly to Williamsport, a distance of 7 miles, the contrast is truly remarkable; and one standing on the limestone along the Greencastle Turnpike anywhere within this distance and looking westward sees a steep and continuous slope, almost an escarpment, rising sharply, sometimes as much as 100 feet or more above him. This slope marks the eastern contact between the shale and the limestone. The western contact is not marked by a continuous escarpment, but every road passing from upland remnants on the shale to the limestone passes from elevations above 500 feet to those under. Within the shale belt thus topographically defined, Conococheague Creek, entrenched 150–200 feet, makes eleven meander bends (Fig. 2). In addition, the map shows at least two abandoned high-level meanders, so that in a distance of 8 miles, between the Pennsylvania boundary and the Potomac River, the Creek has had a total of thirteen meanders. In this distance its present length is about 25 miles, and with one possible exception it is confined entirely to the shale. Most meanders lie wholly within the shale belt and do not reach the contact. But the meander crossed by the Cumberland Road west of Huyett shows limestone on the outside but not on the inside of the curve, as does also the next westward meander to the north. Here the suggestion is strong that the stream swung outward on the undercut slope until it reached the limestone, which has retarded further lateral migration.

A possible transgression onto the lime-

stone occurs on the westward-swinging meander west of Cearfoss.[3] Inspection by the writer disclosed limestone in the western part of the stream channel and the undercut slope at this point, although the contact was not located. Thus, along the Conococheague there is a record of very remarkable, perhaps perfect, adjustment, made more impressive when it is considered that this is the only belt of shale in this part of the Great Valley and that it is paralleled by belts of limestone several times its width to east and west.

To explain this remarkable adjustment, *Guidebook 7*, as indicated in Figure 1, suggests that the Conococheague was flowing at or above the level of the Schooley peneplain in a meandering course about 1,500 feet above its present elevation. At that time it was meandering along the axis of the same syncline as now, but on weak Silurian shales between homoclinal ridges of the resistant Tuscarora sandstone. When the post-Schooley uplift occurred, the Creek is supposed to have cut downward through the ridge-making Tuscarora sandstone and the Juniata formation, respectively 270 and 400 feet thick,[4] and to have retained its inherited meandering course on the Martinsburg shale at the level of the Harrisburg peneplain. This explanation avoids the problem of the relative resistance of the limestone and shale. According to this solution, the Conococheague was formerly a subsequent stream flowing in a synclinal valley between parallel homoclinal ridges of the Tuscarora.

This interpretation seems unacceptable. While an earlier stream may have occupied the synclinal valley postulated, this valley would have narrowed in the course of regional reduction, and the two homoclinal ridges would tend to approach each other, finally to merge as a synclinal ridge. Thus the synclinal valley would have disappeared, and the stream would have been dismembered and entirely destroyed by headward-growing obsequent streams, according to well-recognized principles of folded mountain evolution. The vulnerable position of the earlier stream to such modification seems sufficient alone to rule out the hypothesis of an inherited course for the Conococheague.

In addition, it is to be doubted whether a stream cutting downward through 1,500 feet of rock between its former position on the Schooley peneplain and its present elevation would inherit so precisely adjusted a course on a lower formation. Furthermore, it is not likely that, if such a remarkable adjustment were attained by inheritance, it would have been maintained through two post-Harrisburg rejuvenations unless there were some special continuing virtue in a position on the shale.

To avoid these difficulties, the writer suggests that the Conococheague first achieved its present course as a new subsequent stream *during* the denudational interval *between* Schooley and Harrisburg time and that the Creek was already well adjusted to the shale by the time the Harrisburg peneplain had been made. This interpretation requires that the Valley limestones be weaker than

[3] The 1933 edition of the geological map of Maryland shows the meander bend to be about 0.3 miles west of the limestone-shale contact. The 1931 edition of the geological map of Pennsylvania, however, shows the contact at the state boundary, 1 mile north of the meander bend, about 0.5 miles farther west than does the Maryland map; while R. S. Bassler ("The Cambrian and Ordovician Deposits of Maryland," *Maryland Geol. Surv.* [1919], see map, Pl. I, and p. 156), who noted that the Conococheague was confined to the shale, depicts the bend and the contact as coinciding on his geological map.

[4] Stose, *op. cit.*, columnar section following p. 19.

the shales toward chemical attack but more resistant toward mechanical erosion by streams. Freeman Ward[5] has pointed out that the Somerville peneplain corresponds with remarkable exactitude to those areas underlain by limestone, while the higher Harrisburg remnants are, with similar exactitude, restricted to the shale. He has also shown that streams flowing from the shale to the limestone have broader floodplains in the shale than in the limestone, a fact pointing to the superior resistance of the limestone toward stream corrasion, if the formation of floodplains by lateral corrasion is accepted. These and other facts observed by Ward demonstrate well the opposite ways in which the shale and limestone of this region react to attack by chemical and mechanical agencies.

The most obvious explanation of the subsequent course of the Conococheague would seem to demand that during the Harrisburg cycle the climate be more arid than during the Somerville and that chemical reduction of the limestone be less effective than mechanical attack on the shale, so that a subsequent lowland was developed on the shale by differential denudation. With a more humid climate in Somerville time, the limestone areas were rapidly reduced by solution, while the shale areas remained largely at their former levels except where stream-dissected. This explanation seems adequate; but, with little supporting evidence pointing toward a sufficiently more arid climate in the eastern United States during Harrisburg time, it is difficult to accept. True, the Somerville peneplain is dated as beginning Pleistocene, a time generally taken as one of exceptionally high rainfall and atmospheric moisture. On the other hand, it cannot be definitely stated that the climate of the Harrisburg cycle was so much less humid that the limestone would then have acted as the stronger rock.

The present elevation of the Conococheague, at least 100 feet below the surface of the limestone country, suggests, however, that the Creek could have gained its subsequent course in a humid climate. It is evident that concentrated linear erosion by the Conococheague has been more effective in lowering it toward baselevel than have dispersed areal solution and stream erosion of the limestone. If this were not so, the limestone country, and not the Creek, would be the lowest feature in the landscape. Since in a humid climate the shale has thus been proved to be so susceptible to stream erosion that the Conococheague has maintained itself consistently at elevations below the limestone, it appears that streams developing on the shale have an advantage over those on the limestone. During the Harrisburg cycle the Conococheague was such a stream and not only did it successfully extend itself along the belt of shale, but it entrenched itself so well that it became the master-stream of the shale and of the adjacent limestone country as well. Zones of limestone several miles wide were thus made tributary to the Conococheague by streams now rising in the limestone and flowing into the shale hills to reach the Creek, which is, for them, local baselevel.

While the Conococheague provides the most remarkable example of adjustment to the shale, it is far from being an isolated case. Conodoguinet Creek, rising north of Chambersburg, flows for the greater part of its course to the Susque-

[5] "The Role of Solution in Peneplanation," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 262–70.

hanna River on shale, although the southern half of the Great Valley is here reduced to a limestone lowland. Swatara Creek, east of Harrisburg, flows for many miles along the shale belt, then, without the slightest deflection, crosses the limestone. In West Virginia and Virginia, Opequon Creek, flowing northeastward into the Potomac along the same shale belt as the Conococheague, shows an adjustment almost as perfect as the latter for about 30 miles along the strike. It is probably not without significance that the Potomac itself is offset about 6 miles to the southwest as it crosses the shale belt. Farther south in the Valley of Virginia, the same tendency of the streams to avoid the limestones is apparent, although it is less striking than in the instances cited.

The subsequent course of the Conococheague is of interest in itself and, when considered with other similar cases, strengthens Ward's conclusions that the Somerville peneplain was due to solution and that, in spite of its lower elevations, the limestone is more resistant than the shale toward mechanical erosion. Thus is explained the apparent anomaly in the position of many Great Valley streams.

MUNITIONS BEGIN UNDERGROUND

E. B. BAILEY
Director of the Geological Survey of Great Britain, London

At the outbreak of the war the Geological Survey, one of the many branches of Britain's Department of Scientific and Industrial Research, put aside all its usual preoccupations. It ceased to produce maps and memoirs, except for a restricted issue of wartime pamphlets created for the occasion. Instead, it reorganized its research and other activities so as to be in a position to give advice at short notice to appropriate authorities under three main headings, namely: (1) home mineral resources, to meet essential needs, further aggravated by the economy of shipping and foreign currency; (2) underground water, for new airfields, camps, and factories; and (3) subterranean facilities for storage and personnel.

One example was immediately afforded of the new value which accumulated knowledge may sometimes acquire under changed circumstances. London presented so obvious a target to the enemy that a call arose for prompt reinforcement of many of its buildings. The Geological Survey was asked to indicate interior sources where sand suitable for filling sandbags might be obtained. This it could do at once from its existing maps, pointing to particular parks and public spaces. The Civil Defence authorities have estimated that the resultant sandbagging of London cost £125,000 ($500,000) less than would have been the case if the sand had been brought from operating pits situated outside the built-up area. I quote this estimate merely to give an idea of the scale of the transaction. The essential needs of the moment were speed of acomplishment and noninterference with river, railways, and external roads required for military traffic or evacuation of children.

Until the war no sand worked in Britain was of the extreme purity requisite for the optical glass employed in many of the instruments used by the forces. This presented no immediate difficulty, for optical-glass sand was of very low peacetime value, since it could be conveniently shipped in bulk from Holland, Belgium, or northern France. In June, 1940, however, values changed abruptly —almost overnight.

Fortunately, the Geological Survey had, as long ago as 1921, located a home source of optical-glass sand of the highest quality. The occurrence is situated in a remote district, but its importance as a potential strategic reserve had been constantly stressed in the proper quarter. Thus, in the difficult days that followed the Battle of France, supply of optical-glass sand was maintained without any interruption.

Coal is at all times the main mineral asset of Britain. Its continuous extraction is forever bringing new facts to light. It is natural, therefore, in times of peace, that watching, recording, and advising on the progress of coal-field development occupy a major proportion of the Geological Survey's attention. For a period after the fall of France the output from established mines produced a superfluity; but, with armament factories coming daily into operation, this stage was soon

left behind, and any additional source had to be eagerly considered, if only it seemed likely to produce fuel at a low manpower cost.

Owing to the antiquity of coal-working in Britain, there were, at the outbreak of war, very few records of the extent to which near-surface coal had been extracted, for most modern collieries operate at considerable depth. A thorough investigation was therefore started; and it was soon found that an unexpected proportion of near-outcrop coal had been spared, especially in the Nottingham-Derby-Yorkshire coal field. Here, fortunately, the seams are inclined at so low and steady an angle as to make them ideal subjects for opencast working with modern mechanical excavators.

Opencast, or crop-working, has now been intensively developed. The Geological Survey and its sister-department, the Fuel Research Station, have given assistance—the geologists in location of sites, and the fuel researchers in estimation of quality. When a site has been suggested by the Geological Survey, it is explored by boring and trenching to prove the local conditions, including freedom from old working. If all goes well, production follows—production according to a carefully devised plan in which the surface is returned to agriculture as quickly and as effectively as possible.

Outcrop working started on a small scale toward the close of 1941. Up to the end of April, 1943, over 2,000,000 tons had been produced; by the end of December, this figure had risen to 5,500,000 tons.

In Britain iron ore comes second only to coal in importance. Iron ore today is mostly won from bedded deposits of the Jurassic Age in the English Midlands, exploited, as in the case of coal crops, with mechanical diggers.

The rocks of the Midland ironstone fields include a considerable proportion of clays and have often adjusted their disposition to meet changes of load introduced, very gradually, by the natural excavation, or erosion, of the local valley system. Much additional insight into these adjustments has recently been obtained, and the knowledge gained has helped quarry-managers in the laying-out of working faces. Other assistance has been given through identification of fossil bands in the rock cover. The outcrops of these bands, when mapped, furnish natural contour lines defining the depth at which iron ore is to be expected at any particular locality.

Low-phosphorous iron ores in Britain are almost all replacements or veins. The Geological Survey has guided successful development of certain previously abandoned veins in the Pennine metalliferous field.

Much attention has been given in a number of districts to veins of lead, zinc, tin, and wolfram, so as to assist in meeting war shortages. The spars which accompany the nonferrous metal area have proved of equal importance. The Geological Survey warned the steel industry of a possible fluor shortage and thus helped to avoid an industrial difficulty. One important step was to interpret the shape of a particular fluor body, which allowed of ordered replanning of mining operations.

Several other minerals could be listed which the Geological Survey has usefully investigated during the war including refractories for furnaces, feldspar for pottery, limestone or agriculture, and mica for electrical apparatus. In feldspar, Britain, through Geological Survey advice, has passed from zero production to wartime self-sufficiency, even in the

most exacting grades required for dentures.

The Survey has collected and correlated much geological information about wells sunk in Britain. Already during the war 11,500 entries for wells over 20 feet in depth have been made. The details given include the measured geological section and the diameter of each well and all available hydrological information regarding the depth at which water was struck, the rest-water level, the pumping-water level, the yield, and the quality. The Air Ministry has treated the Survey as its consultant in regard to sources of underground water for the many airfields now scattered over Britain.

REVIEWS

Structure and Evolution of Palestine with Comparative Notes on Neighbouring Countries. By LEO PICARD. (Bulletins of the Geological Department, Hebrew University, Vol. IV, Nos. 2, 3, and 4.) Jerusalem, 1943. Pp. 134; figs. 18.

The author explains in a Preface that this article is not in the form in which it was to have been presented before a Middle East Geological Congress, since the latter did not assemble, but is designed to serve two ends: namely, to inform fellow-geologists and also to describe the geology to the general public. The subjects differ, accordingly, not only in subject matter but also in treatment.

Part I deals with depressions and mountain structure. The relatively low Jordan Valley on the east and the coastal plains on the west are identified as longitudinal depressions. Two transverse depressions, the Emek on the north and the Beersheba on the south, transect the mountain mass, trending northwest. A number of minor depressions, "like big holes or scars, disfigure the otherwise uniform face of the landscape."

The depressions are said to be nearly all of tectonic origin. They are "depressed troughs, which generally originated in two considerable border faults and may be designated as Graben or rift valleys." They are surrounded on all sides by faults and form "radially downfaulted areas." Some other depressions are described as "fold-bends (monocline, syncline)." The distribution of these structures is summed up in the following statement:

> The mountains of northern Palestine, Samaria, and Galilee are rich in collapse depressions; whereas the south—the Judean highland from El Lubban to Beersheba and the Negeb—shows but little or nothing of the phenomenon, although there is no lack of faults in the southern area. The fractures and faults are younger structures, originating for the most part at the end of the Tertiary or the beginning of the Quaternary.

Under the heading "Mountain Structures" the author distinguishes folds, upwarps and downwarps, and fractures. His meaning is more explicitly set forth in the following, under the heading "Tectonics":

> We distinguish three fundamental tectonic forces: folding, warping, and fracturing. From these emanate the structural elements as follows:
>
> *Folding*, which leads to a series of anticlines and synclines, mainly of Middle Tertiary age.
>
> *Warping*, which causes later, i.e., in the transition from Tertiary to Quaternary, upwarps or arches and basins (anticlinorial and synclinorial regions).
>
> *Fracturing*, which produces double bordered rift valleys and horsts, or single bordered fault blocks and tilted blocks, mainly of Older Quaternary origin. There exist also blocks and depressions due to Tertiary faulting; but these faults are less pronounced morphologically, unless they are rejuvenated by Quaternary movements.

Following this summary of tectonic processes is an enumeration of the several structures pertaining to each type. There is an outline map of the structures and a series of cross sections. The map presents the well-known anticlines of the Palestine plateau, trending northeast-southwest. The sections express the author's interpretation of the faults as hading to the downthrow. He adheres throughout the paper consistently to the hypothesis of tension and collapse, in accordance with the views of Suess and Blankenhorn, and fails to mention the fact that the alternative explanation, which substitutes compression for tension, has been preferred by some other geologists who have studied the region (B. Willis, "The Dead Sea Problem," *Geol. Soc. Amer.*, Vol. XXXIX [1928] and "Welling's Observations on Dead Sea Structure," *ibid.*, Vol. XLIX [1938]). The reader might be left in ignorance of the fact that the older view had been challenged.

Part II treats of the "Evolution of Palestine," covering the paleogeography of western Arabia and adjoining lands from pre-Cambrian to Quaternary. The earliest recognized feature is a belt of sediments, which the author compares with the Molasse of Switzerland and interprets as the waste of a mountain range comparable to the Alps. It extended from Transjordania to Abyssinia in pre-Cambrian time. The heights having been reduced to a peneplain before the Paleozoic, the subsequent history is represented by advances and retreats of the sea across the western part of the continental mass. Block diagrams illustrate the author's concepts of suc-

cessive oscillations, back and forth, and the fluctuations of the shoreline from east to west and vice versa are indicated in a diagram for all periods since the Cambrian. It appears that the sea advanced across Transjordania into Saudi Arabia during the Ordovician, Gothlandian, and late Cretaceous and repeatedly invaded Transjordania. To the eastward of the shoreline at any time, extensive continental formations, chiefly of sands, were spread, and they now constitute the monotonous Nubian sandstone of various dates, including marine members.

The stratigraphy and paleogeography of post-Eocene Tertiary (Oligocene to Pliocene) are discussed in detail. Divergent views regarding the occurrence of lower Miocene, Burdigalian, in Palestine and Egypt are offered. Marine and continental Miocene formations are described and mapped. Similar treatment at greater length is given the Neogene and Pliocene, with excursions into Syria, Egypt, and Iraq.

A transition from Pliocene to Pleistocene is set off as the time when warping and "epeirogenic" movements resulted in general faulting from northern Egypt to Syria and produced the great grabens. The reader who wishes to follow a description of the details of faulting and folding will find them set forth in pages 81–84.

The Quaternary is presented in a discussion covering the last sixty-odd pages with a degree of detail which is out of proportion to the length of time involved but is justified by the importance of the local formations in relation to human history. Marine Quaternary, the development of the coastal plain, the nature of the calcareous sandstone, Kurkar—these are some of the more important items discussed. A useful table on page 102 summarizes the movements of the coastal plain and correlates them with anthropological epochs from Acheulean to Mousterian. The Quaternary of the Jordan Valley is accorded special notice, with a structural diagram. Climatic changes and Pluvial and inter-Pluvial periods are indicated. A chronological table of Pleistocene events sums up the record (pp. 122–23). Finally, a brief "Retrospect" condenses the long story from pre-Cambrian to the present in four pages.

In *Structure and Evolution of Palestine* Professor Picard has assembled the results of more than a score of years of exploration and painstaking observation. Students of the geology of the Middle East will regret that he has been obliged to present his findings in so condensed a form, but they will nevertheless find this work of notable value, especially in the subjects where he is most at home, stratigraphy and paleontology.

BAILEY WILLIS

"Surface Trace of the 1855 Earthquake." By M. ONGLEY. (In *Transactions of the Royal Society of New Zealand*, Vol. LXXIII [1943], pp. 84–89 [map and 12 photographs].)

"Wairarapa Earthquake of 24th June, 1942, together with Map Showing Surface Traces of Faults Recently Active." By M. ONGLEY. (In *New Zealand Journal of Science and Technology*, Vol. XXV B [1944], pp. 67–78 [2 maps and 15 photographs]).

Interest in fault scarplets and their distribution, with its bearing on earthquake frequency and long-range prediction in certain districts, has been growing for some years in New Zealand. This interest has been stimulated recently by the occurrence of an earthquake which shook the Wellington province, causing considerable damage, especially at Masterton, in the Wairarapa district, on June 24, 1942, and by the discovery that the cause of this disturbance may be traced to movement on a near-by fault, which shows surface displacement most strongly marked on hills about 3 miles north of Taueru and with 10 miles of the town of Masterton. The author describes the scarplet and associated features along this line of disturbance.

His investigations of the scarplets, formed when a large earth block was tilted contemporaneously with the occurrence of the great Wellington earthquake of 1855, were made some years ago and are now published with full references to early accounts of the events. The line traced by these breaks closely follows the base of the eastward-facing fault-scarp front of the Rimutaka Range from a point near Palliser Bay, continues northeastward through the Wairarapa district, parallel to the base line of the Tararua Range (these are western or backbone ranges of the North Island), and next swings farther to the east into the lower ranges east of the intermontane basin occupied by the Manawatu River and its tributaries. "Although the fault trace has not been followed from end to end, it has been followed so far and picked up at so many other points that there is little doubt that it is continuous." At its northeastern end it "runs into

the old fault" bounding the isolated Waewaepa Range on the eastern side, "where the beds have moved thousands of feet." In all but two of the many places where it has been observed the upthrow (in 1855) has been on the western side and has amounted to 3–10 feet. Commonly there is a scarp higher than this along the line of the fault, but it "can be seen to be composite, consisting of a fresher break about 6 feet and older breaks forming a grassed step 20–50 feet high."

Such facts indicate that the 1855 movement was the latest of two, or probably more, displacements on the same fault surface; but it is made clear that the majority of the scarplets along this trace were not on, or even very close to, the line of any of the faults of tectonic importance that bound major block features. The author does not discuss the question whether the newer line of break is one of gravity subsidence only rather remotely related to a thrust fault or whether there has been, on this line, renewal of upthrust along a surface parallel to, or branching from, an older major dislocation. He quotes contemporary accounts, however, of actual uplift (with tilting of a broad strip of country) which took place on the upthrow side of the new fault at its southern end. He describes a single exposure of the outcrop of a fault (a branch from the main fault?) of the older system as revealing "a low-angle thrust dipping less than 30°." This is at the south end of the area affected; and the fault is more or less parallel to, but not actually at, the base of the Rimutaka Range, being three-quarters of a mile east of it. The overthrust side consists of rocks similar to those in the range, "probably Palaeozoic, and the east side is light, loose river conglomerate probably Pleistocene."

The simple nature of the movement of 1855 and its immediate predecessors is most apparent where the resulting scarp crosses nearly level ground (see Fig. 2 [Ongley's Fig. 11]). There is little indication of scissors faulting along most parts of the scarp or fault trace, though Ongley notes that "in two places the east side has been raised 6 to 10 feet." At a number of the outcrops of the fault, however, a notch has been developed at the scarplet by fault movement with downthrow in the regular direction (to the east), because at these points the fault intersects spurs and foothills with westward surface slopes (see Ongley's Figs. 4 and 9). (There are some similar features along the lines of scarplets in the vicinity of Wellington city.)

In some of the numerous localities in which scarplets have been described, in both the North and South islands of New Zealand, to which the author refers in his Wairarapa paper, these are of the nature of "earthquake rents" or "reverse scarplets," as the reviewer now prefers to call them, which not only notch spurs but also develop trenches that extend for miles across spurs and ravines. These the author does not distinguish from ordinary scarplets. Their nature indicates, however, that the latest movements on the major faults underlying them have been in a direction the reverse of earlier movements; and such features, as a whole, do not lend themselves to the alternative explanation that they are merely spurs notched in the manner described in the preceding paragraph.

FIG. 1.—Scarplet formed in 1942, 3 miles north of Taueru, Wairararapa district (*N.Z. Jour. Sci. and Tech.*, Vol. XXV, p. 70, Fig. 4). Photo by M. Ongley.

FIG. 2.—View looking south along scarplet 5 miles west of Masterton (rejuvenated in 1855) (*Trans. Roy. Soc. N.Z.*, Vol. LXXIII, Pl. 17, Fig. 11). Photo by M. Ongley.

In a map (7 × 12 inches), accompanied by an extensive list of references to authorities, which is issued with the Wairarapa paper, an

attempt has been made to show all known scarplets and earthquake rents indicative of "recent" earthquake-making fault movements in central New Zealand. These are all between Lat. 38° and 44° S. Quite justifiably, from the utilitarian point of view of long-range earthquake prediction, no distinction is made in the map between ordinary and reverse scarps. It may be noted, in passing, that the Hawke's Bay (1931) scarp is shown about 10 miles too far north: it passes south, not north, of the town of Napier.

The Masterton, or Taueru, scarplet (1942) crosses the top of a hill, peters out, and reappears beyond a small valley. It is very far from any ancient fault of tectonic or, at any rate, of topographic significance but has been the site of some small earlier (but recent) movement. Although fissuring and disturbance of the ground accompanied by slips and slumping of river banks close to the line of movement can be traced for some miles, well-marked scarps occur only along about three-quarters of a mile of an easterly to northeasterly trending trace. The new break makes a scarp which is nowhere more than about 3 feet high; but, since in places fresh cracks with this displacement are "in the foot of a face 10 feet high, it looks as if in the recent earthquake the ground has moved once more along a line where it had previously moved three or four times as much."

C. A. COTTON

David Dale Owen: Pioneer Geologist of the Middle West. By WALTER BROOKFIELD HENDERSON. ("Indiana Historical Collections," Vol. XXVII.) Indianapolis: Indiana Historical Bureau, 1943. Pp. xiii+180; figs. 7.

It is a pleasant change in these days of advanced, specialized research to turn to an intimate account of the first geological surveys undertaken in some of our middle-western states. Especially interesting this proves to be because a lively central figure—David Dale Owen—unifies several of these pioneer efforts in a connected story.

David Dale Owen, broadly trained in Scotland, Switzerland, London, and Cincinnati, was primarily a chemist until his thirtieth year. But in 1837 the Indiana General Assembly authorized an investigation of the mineral deposits of the state, and young Owen was selected for this. With great energy and enthusiasm he set out on a solo reconnaissance, differentiated the Carboniferous from the sub-Carboniferous (which at first included everything below the coal measures), came to suspect from the gentle dips that the coal beds found in Indiana were but a part of a large deposit that spread into Illinois in the form of a basin, and before the end of the year presented his report. This Indiana survey, however, soon gave way to a more urgent project.

For many years the policy of Congress had been not to sell but to lease public lands which contained mineral resources. The designation of specific mineral areas was in the hands of the surveyors of the Land Office, but, as none of them had the special training required for the work, mining reservations were located in a hit-or-miss fashion, many disputes arose, and trouble piled up. The problem became a major one after Black Hawk's defeat in 1832 when the land ceded by him to the United States was opened to settlement. Both miners and farmers rushed in, as northeastern Iowa and adjacent Wisconsin and Illinois were known to contain lead ore and were likewise desirable agricultural country. The demands of the two groups conflicted.

On August 17, 1839, Owen, at his home in New Harmony, Indiana, received notification of his appointment as principal agent to explore the mineral lands of the United States and, with it, detailed instructions for a complete survey of the region which might contain lead ore. This was all to be completed before winter set in. Working against time, Owen gathered together a score of his fellow-townsmen who had heard some of his popular lectures, proceeded to St. Louis, where several score additional men were hired, and then drilled his army on the fundamentals of geology and surveying on the steamboat trip up the Mississippi. They landed at Rockingham, Iowa, September 17, and promptly deployed in twenty-four squads. What followed is interesting reading. In spite of many difficulties, Owen's capable generalship brought the task to a successful completion on November 24, just before a severe snowstorm set in and the temperature dropped to 12 or 14 degrees below zero.

Probably the high point in Owen's career was the Wisconsin, Iowa, and Minnesota survey in 1847–49, which took him to places where no white man had been. He penetrated Canada, and an assistant reached the Bad Lands of South Dakota, bringing back a large number of fossils hitherto unknown. Naturally

only the main geologic features could be discovered in traversing such large areas, yet the results and their skilful presentation by the indefatigable Owen turned the eyes of American and British geologists toward various new questions. Congress had demurred over the high costs entailed by Owen's ambitious plans for printing, but in the end yielded to his insistence that his plates, sections, and maps required new standards of reproduction as well as quarto size instead of the octavo format used for government publications.

The last six years were the most crowded of Owen's overcrowded life. Along with various other activities he made a geologic survey of Kentucky in the first three and of Arkansas in the last three, in spite of failing health and recurring fever. As Indiana was then seeking him for a new survey of his own state, he drove hard to finish the Arkansas reports—too hard, in fact, for his life had been too busy, and he literally worked himself to death at the early age of fifty-three.

Owen was temperamentally, as well as by circumstances, a pioneer placed in a new country. His quick mind turned eagerly to new and unexplored fields, one after another of which he explored with amazing industry. Naturally, he made mistakes which a more careful man might not have made. But the latter would not have accomplished what Owen did. The mistaken ideas today are interesting in themselves. Actually he placed the nomenclature of western formations on a firm foundation and, in so doing, helped to standardize names throughout the United States. It is partly because Owen courageously insisted that our geologists renounce their individualism and accept the Cambrian and Silurian of Sedgwick and Murchison that today Americans and Europeans talk the same geological language because of a universal name system.

One closes this interesting and well-written book with a feeling of high admiration for the enthusiastic, many-sided David Dale Owen.

R. T. C.

Optical Crystallography. By ERNEST E. WAHLSTROM. New York: John Wiley & Sons, Inc., 1943. Pp. 206; figs. 209. $3.00.

This small book is divided into seventeen chapters. The first two serve as an introduction to crystallography; the next four deal with isotropics and elementary optics and the microscope; the following six with uniaxials; the succeeding four with biaxials; and the final chapter is a sort of summary laboratory outline. The point of view is that of the mineralogist and not the chemist. In general the treatment, which is nonmathematical in the main, is lucid and simple; the numerous line drawings, many of which are stippled, constitute the most valuable part of the work. Both indicatrix and ray-velocity models are employed. While, in detail, the book is quite different from Winchell's *Optical Mineralogy* (Part I), in general content and mode of coverage the two are so similar that it is surprising that one publisher should put out both of them.

Wahlstrom's book would be better without the first two chapters; the attempt to cover morphology in 8 pages is full of inaccuracies, in part because crystals are treated as if they were wooden blocks. Three projections are described in 6 pages; no later use is made of the gnomonic; the stereographic serves to illustrate a triclinic crystal (p. 130) but in out-of-date orientation; and the orthographic is employed for a too-brief treatment of skiodromes. Physical properties are covered even more succinctly in the 3 pages of chapter ii. The treatment of extinction angles is far too brief; description of the methods of determining sign from interference figures is unnecessarily extended. The subjects of conical refraction and dispersion of the optic axes are well handled.

In a number of places "the index of refraction of violet light" is mentioned. Light has a velocity, the substance being traversed has the index. "Quartz glass" (p. 34) should not be used to mean "silica glass." A substance does not have a higher index for red and a lower one for blue (p. 43); correct statements appear on pages 33 and 53. The quartz wedge does not resolve white light into its spectrum (p. 79). Some of the figures are incorrect; thus the upper figure on page 42 should show diverging rays extending to the left above the grain. In the left-hand figure on page 61 the rays leaving the crystal on the right should not show differing wave-lengths in air. The numbers are reversed on the third diagram, page 64. The rays on page 84 should show both smaller amplitudes and shorter wave-lengths in the crystal plate than are shown in air. On page 89 converging light striking the condenser emerges as parallel light. Such errors of detail are easily corrected. On the

whole, the book will appeal to many teachers. With the exceptions noted, it is a praiseworthy piece of work.

D. J. F.

"The Haplolepidae, a New Family of Late Carboniferous Bony Fishes: A Study in Taxonomy and Evolution." By T. STANLEY WESTOLL. (*Bulletin of the American Museum of Natural History*, Vol. LXXXIII [1944].) Pp. 1–122; text figs. 52; pls. 10.

The title of this study tends to obscure its actual scope. The report, by virtue of its analysis of the evolution of the actinopterygian fish, is, in reality, one of the most important papers on fossil vertebrates published during the last several years. In the first sections of the work the author describes in great detail a group of late Carboniferous fish which he refers to a new family, the Haplolepidae. Two genera—*Haplolepis*, with nine species, and *Pyritocephalus*, with five—are recognized as representatives of the family. Two familiar generic names of late Paleozoic fishes, *Eurylepis* and *Mecolepis*, both preoccupied, are shown to be synonymous with *Haplolepis*. Descriptions of the species are detailed; and the illustrations, which consist of reconstructions of the species, detailed sketches of actual materials, and reproductions of photographic plates, are excellent. Had the paper merely included the descriptive sections and illustrations, it could have been considered a sound contribution to the knowledge of Paleozoic fish. It is, however, in the application of the morphological data to studies of evolution that the work becomes of outstanding importance.

The most significant parts of the report are concerned with the evolution of the family Haplolepidae and with its bearing upon the course of development of the actinopterygians as a whole. It is shown that similar changes of skull and body appeared independently in different evolutionary lines not only within the family but also later among the "Holostei" and "Subholostei." These changes do not, however, appear in combination solely in one later family, which then might be thought to have descended from the Haplolepidae, but rather in various associations in several distinct groups. This raises the question of the validity of the customary use of such characters in classification.

The evolutionary concepts are elaborated in the section titled "Bearing on Holostean Evolution," in which the author concludes that the polyphyletic origin of the "Holostei" is clearly indicated. The "order" is not natural but has been derived from more than one Paleozoic family and represents an evolutionary grade of development reached independently by several groups. In short, Westoll regards *all* actinopterygians which are different from the palaeoniscids as "forming a fringe of evolutionary twigs and branches around a compact ancestral bush. . . ." The unity of the Teleostei is such that this term is significant in classification, but neither the group "Holostei" or "Subholostei" can be considered valid.

A most interesting section is that designated "General Remarks on the Evolution of the Actinopterygians," in which the author analyzes the relationships of the fish to their environment on the basis of a study of the mechanics of swimming. The correlation of changes in adaptations with changing environment gives the basis for his concept that "parallelism" has resulted—in large part, at least, from similar environmental impact on various groups, particularly in the change from nonmarine to marine environments, rather than from comparable mutations of similar genes in related lines, as presented by Brough. Westoll's argument is strengthened by recognition of significant time intervals, implying "millions of generations," between the appearance of similar changes in different groups.

The final sections of the paper consider the biological and physical environment and the distribution of the family Haplolepidae. The haplolepids lives in nonmarine, shallow, somewhat stagnant, waters. The wide distribution of the family implies intercontinental connections between the areas in which its members have been found. The bearing of the distribution upon the theories of continental drift and the permanency of continents is considered briefly, with the author leaning, without decisive evidence from the haplolepids, toward the concept of continental drift.

The study has a concise, two-page summary, addenda of relevant work published since it was written, and an excellent list of references which are cited throughout the body of the text.

EVERETT C. OLSON

Mineral Resources of Minnesota. Edited by WILLIAM H. EMMONS and FRANK F. GROUT. (Minnesota Geological Survey Bulletin 30.) Minneapolis: University of Minnesota Press, 1943. Pp. viii+149; figs. 25.

Introduced by a brief discussion of the general geology of the state, this report gives concise accounts of the occurrence, origin, and utilization of Minnesota's various mineral resources. Of greatest importance and first in interest are the iron ores of the Mesabi, Vermilion, Gunflint, and Cuyuna ranges, which naturally receive the most attention. Already the cover of glacial drift stripped from the ore bodies of the Mesabi Range bulks about twice as large as all the material excavated in constructing the Panama Canal. By the end of 1941 this range had shipped 1,180,000,000 gross tons of iron ore, while the total for the whole Lake Superior region was 1,932,000,000 tons. About an equal quantity of proved high-grade ore still remains. Eventual use, by beneficiation, of the enormously greater masses of taconite, or cherty iron formation, is discussed in the light of possible competitive iron ores.

In Minnesota there is very little high-grade manganese ore (containing more than 45 per cent manganese), but the manganiferous iron ores of the Cuyuna Range may prove to be a large factor in the national manganese supply if and when foreign supplies are not available, although in normal times manganese cannot be produced from them profitably in competition with foreign ores.

The various other mineral resources are treated approximately in the order of their commercial importance.

R. T. C.

X-ray Crystallography. By M. J. BUERGER. New York: John Wiley & Sons, 1942. Pp. xxii+531; figs. 252; tables 34. $6.50.

This work treats of the geometry of crystal structures and the detailed methods of its determination up to the level of finding the space group but not the atomic positions. Crystal physics and chemistry are not covered. Only those techniques are described which make use of single crystals and monochromatic radiation, with especial emphasis on moving-film methods. The necessary theory is developed in lucid fashion, using both vector algebra and more elementary methods. The work is an outstanding one, well-nigh indispensable to the beginner in this field.

D. J. F.

Japan: Its Resources and Industries. By CLAYTON D. CARUS and CHARLES LONGSTRETH MCNICHOLS. New York and London: Harper & Bros., 1944. Pp. xvii+252; photos 67; maps and charts 21. $3.50.

What were the resources and industrial status of Japan at the start of the present war, and what will be the role of Japan in the post-war world are questions of vital interest today. For answers the authors have presented the most authoritative information obtainable on the geographical, agricultural, animal, mineral, commercial, industrial, manufacturing, and human resources of the country, tracing expertly the development of modern Japan and portraying clearly its strong points, weaknesses, and prospects for the future. Much of this material they had been accumulating over a period of years; fortunately, they were able to gather and check considerable new information just prior to the war in spite of the evasiveness and deception of the Japanese.

As the fourth volume in the "Harper Geoscience Series," this is primarily a textbook, yet so much of its substance is of timely, human interest, attractively handled, that it is also a book for the studious general reader. The illustrations mostly are large and effective. Although in some the detail has not reproduced satisfactorily and sharper definition is to be desired, the effect on the whole is pleasing.

Geology is here involved only in the occurrence and production of coal, petroleum, metals, and economic minerals. For up-to-date information on these products and their future possibilities, given rather concisely, the chapter on mining may be commended.

R. T. C.

The Dedication of the State Natural Resources Building and the Illinois Mineral Industries Conference, Urbana, 1944. Illinois State Geological Survey Bull. 68. Pp. 305; figs. 92.

The splendid new State Natural Resources Building, housing the Illinois Geological Survey and the State Natural History Survey, was dedicated on November 15, 1940; but the volume containing the dedicatory addresses and the papers presented at the Illinois Mineral Industries Conference which was held in conjunction has only recently appeared. The principal dedication address, "Our Better Ordering and Preservation," was delivered by Dr. Isaiah Bowman.

Part II, forming the major portion of the volume, comprises the papers presented at the 1940 Illinois Mineral Industries Conference. These are grouped as follows: "Current Research on Coal," three papers; "Economics of Coal," four papers; "Symposium on Devonian Stratigraphy," thirteen papers; "Economics of Oil-Field Practice," four papers; and seven papers under the heading "Industrial Minerals." Although considerably less than half the speakers were members of the Illinois Geological Survey, the many-sided treatment of the state's mineral-resource problems reveals the broad scope of the Survey's investigations developed by Dr. Leighton.

Of outstanding value to the stratigrapher and paleontologist is the symposium on the Devonian stratigraphy of the central states, involving Illinois, Iowa, Missouri, Oklahoma, Arkansas, Tennessee, Kentucky, and Indiana—each treated by a selected authority. These are followed by discussions and a general correlation of Devonian formations in Illinois and the adjacent states by G. Arthur Cooper.

R. T. C.

Colorimetric Determination of Traces of Metals. By E. B. SANDELL. New York: Interscience Publishers, 1944. Pp. xvi+487; figs. 73. $7.00.

The first 110 pages of this book, divided into four chapters, are given over to a general discussion of colorimetric trace analysis, covering methods, precautions, procedures, and reagents. Besides colorimetry and spectrophotometry, some use is made of fluorimetry. The remainder of the work treats of the detailed procedures used for determining traces of forty-five metals and the rare earths; each of these chapters has the twofold division of separations and methods of determination, and many of them also treat of applications. In over a dozen cases one of the "Applications" listed is silicate rocks; other headings under "Applications" include ores and alloys, soils, water, biological materials, etc.

The author has been quite successful in his aim "to present a limited number of methods which at the present time appear to be best suited for dealing with traces of metals." This book should be of great value to analysts working in this field, which is now of so much research interest.

D. J. F.

Soil: The Most Valuable Mineral Resource; Its Origin, Destruction, and Preservation. By W. H. TWENHOFEL. (State of Oregon Department of Geology and Mineral Industries, Bull. 26.) Portland, Oregon, 1944. Pp. 43, figs. 35. $0.45.

In his Eighth Annual Message to Congress, December 8, 1908, Theodore Roosevelt said: "When the soil is gone, men must go; the process does not take long." In this bulletin not only does Twenhofel express his belief that "erosion of the soils is the biggest problem confronting the farmers of the nation over a tremendous part of its agricultural lands," but he chooses to go further and regard it as "the biggest problem confronting the nation as a whole." While prepared primarily for the people of Oregon, this bulletin is designed to impress upon as wide a circle of readers as possible how seriously our most important resource is being depleted through ignorance and carelessness. The many striking photographs from various parts of the country should convince even the unimaginative reader.

The general problem is treated as basically one of geologic processes. To give the reader a correct understanding of the factors involved, the author discusses adequately, but as simply and clearly as possible, the formation of the mantle rock, rates of rock destruction in forming the mantle, and its erosion by wind and water. Free use of quantitative factual information makes the discussions concrete and practical. The last two chapters are "Erosion in the United States" and "Protection of Lands against Erosion."

The keynote of the work is well expressed in the summary: "The foregoing considerations show how geologic processes can be made to work for, instead of against, man; how the water can be made to conserve and not to destroy the soil. Thus, the geologic processes become the friends and not the enemies of man."

R. T. C.